

CHAPTER 13

MATERIALS TESTING

As you know by now, materials testing is a major part of an EAs responsibilities, especially for those EAs assigned to the Seabee construction battalions. The EA3 TRAMAN introduced you to the subject of materials testing. In that TRAMAN, you learned many of the basic soils and concrete tests that an EA performs. This chapter furthers your knowledge of the subject area.

In this chapter you will be introduced to several soils tests that the EA2 is expected to perform. You will study the constituent ingredients used in the production of concrete and will be introduced to many different procedures for testing those ingredients. You will learn about the tests used for concrete mixture design purposes and for determining the strength of concrete. Also, you will study bituminous materials, learn about methods used to test those materials, and will be introduced to various tests used in the design of bituminous pavement mixtures.

Although some of the tests discussed in this chapter are covered in seemingly thorough detail, it is not the intent of this TRAMAN to teach you how to perform the tests; instead, you will learn the purpose and principles of the tests, but only the fundamental procedures. For each test, the discussion identifies an authoritative source that you should refer to for detailed procedural guidance. Always use those sources when actually performing any of the materials tests.

SOILS TESTING

Soil compaction and density testing are two of the most common and important soils tests that an EA must learn to perform. Those tests, as well as the California bearing ratio test and hydrometer analysis, are discussed in this section.

COMPACTION TEST

Compaction is the process of increasing the density (amount of solids per unit volume) of soil by mechanical means to improve such soil properties as strength,

permeability, and compressibility. Compaction is a standard procedure used in the construction of earth structures, such as embankments, subgrades, and bases for road and airfield pavement.

In the field, compaction is accomplished by rolling or tamping the soil with special construction equipment. In the laboratory, compaction can be accomplished by the impact of hammer blows, vibration, static loading, or any other method that does not alter the water content of the soil. Usually, however, laboratory compaction is accomplished by placing the soil into a cylinder of known volume and dropping a tamper of known weight onto the soil from a known height for a given number of blows. The amount of work done to the soil per unit volume of soil is called **compactive effort**.

For most soils and for a given compactive effort, the density of the soil will increase to a certain point, as the moisture content is increased. That point is called the **maximum density**. After that point, the density will start to decrease with any further increase in moisture content. The moisture content at which maximum density occurs is called the **optimum moisture content** (OMC). Each compactive effort for a given soil has its own OMC. As the compactive effort is increased, the maximum density generally increases and the OMC decreases.

The following discussion briefly describes the equipment and procedures of the ASTM compaction test that determines the OMC and the maximum density obtainable under a given compactive effort. You can find a full discussion of the test in *Materials Testing*, NAVFAC MO-330.

Equipment

The principal equipment used for the compaction test is the compaction cylinders and the compaction tamper that are shown in figure 13-1.

There are two compaction cylinders. The smaller cylinder (**Proctor mold**) is 4 inches in diameter and has a volume of 1/30 (0.0333) cubic feet. It is used for materials passing the No. 4 sieve. The Proctor mold is

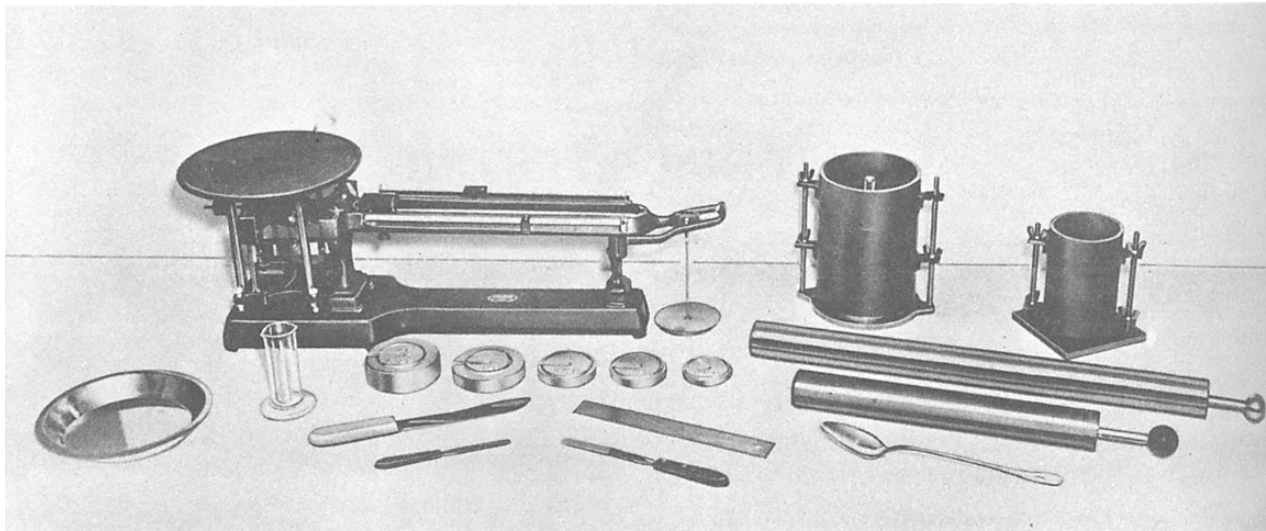


Figure 13-1.—Apparatus for soil compaction testing.

fitted with a detachable base plate and a removable extension collar that is 2 1/2 inches high.

The larger cylinder is the **CBR mold**. It is 6 inches in diameter, 7 inches high, and is fitted with a base plate and a 2-inch-high extension collar. When you are compacting a soil sample, a 2 1/2-inch-thick spacer disk is placed inside the CBR mold to control the thickness of the compacted sample. With the spacer disk in place, the volume of the mold is about 0.0735 cubic feet. The CBR mold is used for samples containing material retained on the No. 4 sieve.

The compaction tamper consists of a drop tamper in a cylindrical guide. The tamper has a drop weight that weighs 10 pounds and has a striking face that is 2 inches in diameter. The guide sleeve regulates the height of drop to 18 inches. To use the compaction tamper, you place the guide on top of the specimen and then draw the tamper to the top of the guide and allow it to drop.

Other items that you need to perform compaction testing are a balance or scale for weighing the material in grams, a 3/4-inch and a No. 4 sieve, moisture canisters, and tools, such as a mixing pan, spoon, trowel, spatula, and a steel straightedge for striking excess material from the top of the mold after compaction.

Sample Preparation and Compaction Procedures

About five specimens, containing successively increasing moisture contents, are needed to

determine the OMC at which the maximum density for a given compactive effort will occur. For the Proctor mold, about 6 pounds for each specimen (about 30 pounds total) is needed. For the CBR mold, you will need about 12 to 14 pounds per specimen, or about 60 to 70 pounds total.

Before the compacting begins, the sample is air-dried and a moisture content of the air-dried material is determined. Airdrying is done by spreading out the material in the sun or in front of an electric fan. The water content of the air-dried material is determined as a basis for estimating the amount of water you need to add to each trial specimen. The driest specimen should contain just enough water to produce a damp mixture that crumbles readily. For each succeeding specimen, increase the water content by about 2 percent until the wettest specimen is quite wet and plastic.

The compaction procedures for nongravely and gravelly soils are the same with two exceptions. First, the 4-inch Proctor mold is used for fine-grained soil, and the CBR mold is used for gravelly soil. Second, 25 tamper blows per layer are used for the Proctor mold, and 55 blows per layer are used in the CBR mold. That results in equal compactive efforts for the two mold sizes and soil volumes.

To compact the soil, you first attach the base plate and collar to the mold. Then you fill the mold to the top of the collar with the material placed in five equal layers, compacting each layer with the appropriate 25 or 55 equally distributed blows. After compacting the

SOIL COMPACTION TEST DATA										DATE 01 SEP 19__	
PROJECT MOTOR POOL		EXCAVATION NUMBER 3		SAMPLE NUMBER MP-P1-3		NUMBER OF LAYERS 5					
CONVERSION FACTORS 1728 cu. in. per cu. ft. 453.6 gm. per lb.		NUMBER OF BLOWS PER LAYER 25		WEIGHT OF TAMPER 10 LB		HEIGHT OF DROP 18"		MAXIMUM PARTICLE SIZE 0.187" (No. 4)			
		SPECIFIC GRAVITY 2.72		DIAMETER OF MOLD (in.) 4.0		HEIGHT OF SOIL SAMPLE (in.) 4.584		VOLUME OF SOIL SAMPLE (cu. ft.) 1/20			
RUN NUMBER	UNITS	1		2		3		4		5	
WEIGHT OF WET SOIL + MOLD	LB.	12.8		13.1		13.3		13.4		13.2	
WEIGHT OF MOLD	LB.	8.7		8.7		8.7		8.7		8.7	
WEIGHT OF WET SOIL	LB.	4.1		4.4		4.6		4.7		4.5	
WET UNIT WEIGHT, $\gamma = \frac{\text{Weight of wet soil (lb.)}}{\text{Vol of soil sample (cu. ft.)}}$	LB PER CU FT	123.0		132.0		138.0		141.0		135.0	
TARE NUMBER		12	13	14	15	16	17	18	19	20	21
A WEIGHT OF WET SOIL + TARE		47.7	44.7	44.1	42.8	44.1	45.6	45.1	46.7	45.2	45.6
B WEIGHT OF DRY SOIL + TARE		46.5	43.6	42.5	41.2	42.2	43.7	42.5	44.0	42.3	42.4
C WEIGHT OF WATER, $W_w (B - A)$		1.2	1.1	1.6	1.6	1.9	1.9	2.6	2.7	2.9	3.2
D WEIGHT OF TARE		22.6	22.2	21.5	20.8	22.2	23.2	21.4	22.5	22.2	21.9
E WEIGHT OF DRY SOIL, $W_s (B - D)$		23.9	21.4	21.0	20.4	20.0	20.4	21.1	21.5	20.1	20.5
WATER CONTENT, $w = \left(\frac{W_w}{W_s} \right) \times 100$	PERCENT	5.0	5.1	7.6	7.8	9.5	9.3	12.3	12.6	14.4	15.6
AVERAGE WATER CONTENT	PERCENT	5.1		7.7		9.4		12.5		15.0	
DRY UNIT WEIGHT, $\gamma_d = \left(\frac{\gamma}{1 + w/100} \right)$	LB PER CU FT	117.0		122.6		126.1		125.3		117.4	
TECHNICIAN (Signature)	COMPLETED BY (Signature)				CHECKED BY (Signature)						

DD Form 1210, AUG 57

Figure 13-2.—Data sheet for soil compaction test.

material, you remove the collar and weigh the mold and compacted material. Then take moisture content samples from the top and bottom of the specimen and determine the moisture content for each. If the two moisture contents differ, use the average between them.

A modification of the above procedure uses a 5 1/2-pound tamper and the material is placed in three equal layers, rather than five; otherwise, the test is the same. The procedures can be found in ASTM D 698.

Data and Calculations

Figure 13-2 shows the test results and calculations for a compaction test. As you can see, this test used a 10-pound tamper and Proctor mold. Five runs were made. After compaction, the weight of the compacted

soil and mold was recorded for each run. From this, the weight of the mold was subtracted to get the weight of the soil for each run. Then the wet unit weight was computed using the formula shown.

Lines A, B, C, D, and E contain the data for the moisture-content test for each run. Note that for each run, there were two tests: one from the top of the mold and the other of soil from the bottom. The averages were set down beside average moisture content. Finally, the dry unit weight (density) in pounds per cubic foot (pcf) for each run was calculated by the formula shown. As you can see, for the same compactive effort, the density varied with the average moisture content.

The ultimate objective of the compaction test is to determine the OMC; that is, the moisture content that yields maximum density for a given compactive effort.

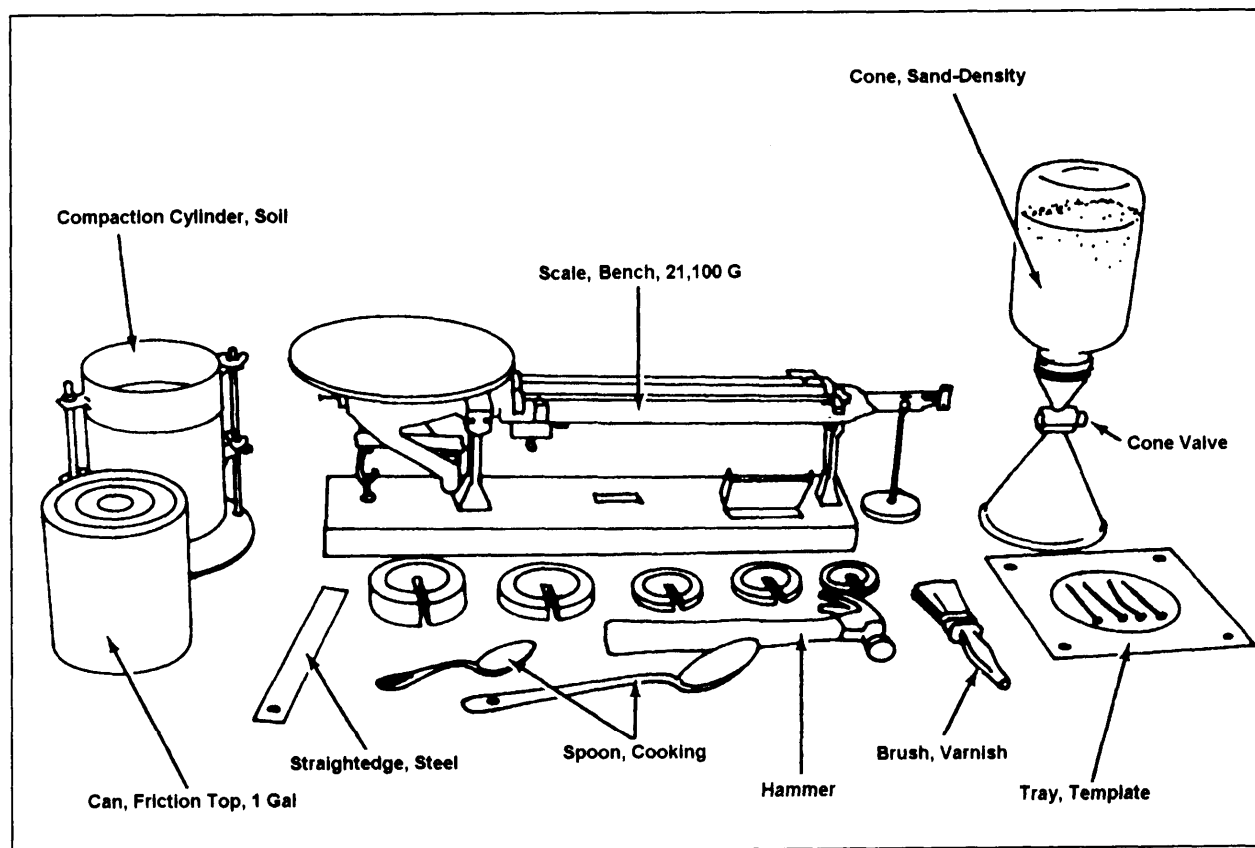


Figure 13-4.—Sand-displacement method apparatus.

required that 98 percent of the maximum density be obtained through compaction. The maximum attainable was 127.2 pcf; 98 percent of this is 124.7 pcf. The dotted line is drawn at the 124.7 pcf level. Any moisture content lying in the crosshatched area above this line would produce the specified density for a given compactive effort; therefore, the range of permissible moisture content is from 9 to 13 percent.

DENSITY TESTS

From the preceding discussion, you know that compaction testing is performed to determine the OMC and the maximum density that can be obtained for a given soil at a given compactive effort. You also know that, using the maximum density, you can determine a range of densities and moisture contents that will satisfy the compaction requirements for a project. During the construction of that project, however, a control must be in place to measure whether or not the compaction requirements have been met. That control is **density testing**. If the results of the density test determine that the compaction process has produced a density within the range specified, then the compaction is complete. On the other hand, if the test results reflect densities that are

not within the specified range, additional rolling may be necessary or the moisture content may have to be adjusted.

Several different methods are used to determine the in-place density of a soil; however, the methods that EAs are most apt to use are the **sand-displacement** method and the **nuclear moisture-density meter** method.

Sand-Displacement Method

A full discussion of the procedures used in the sand-displacement method can be found in *Test Method for Pavement Subgrade, Subbase, and Base-Course Material*, MIL-STD-621A, and in NAVFAC MO-330. This method, often called the **sand-cone method**, may be used for both fine-grained and coarse-grained materials. In general, the test consists of digging out a sample of the material to be tested, using calibrated sand to determine the volume of the hole from which the sample was removed and to determine the dry unit weight of the sample.

EQUIPMENT AND TOOLS.— The essential equipment and tools that you will need to perform the test are shown in figure 13-4. In addition to these, you

Sand No. <u>1</u>	Batch No. <u>A</u>	Date _____
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	1	2	3	Avg
Weight of apparatus filled with water, grams	11,295	11,299	11,303	
Weight of apparatus empty and dry, grams	4248	4249	4250	
Weight of water, grams	7047	7050	7053	7050

Weight of water in pounds = $\frac{\text{Weight in grams}}{453.6} = \frac{7050}{453.6} = 15.542$ pounds

Volume of apparatus = $\frac{\text{Weight water in pounds}}{62.3} = \frac{15.542}{62.3} = 0.249$ cubic feet

Figure 13-5.—Sample data sheet, calibration of sand-cone density apparatus.

will also need a baking pan, moisture content canisters, a paintbrush with moderately long bristles, and some modeling clay.

CALIBRATION.— The sand-displacement method includes three calibration procedures that must be completed before you conduct the test.

The first of the calibration procedures is the **apparatus calibration** that determines the volume of the jar and connecting cone (up through the cone valve). To perform the calibration, you first weigh the assembled apparatus (jar and cone) when it is empty, clean, and dry. Record this weight on a data sheet similar to figure 13-5. Then you weigh the apparatus when the jar and the smaller end of the cone is filled with water (making sure that no air is entrapped in the water). Record this weight on the data sheet and then empty the water from the apparatus. After repeating these steps at least three times, you can then determine the average weight of the water and compute the volume of the apparatus, using the formulas shown in figure 13-5.

The second calibration that you must make before performing the sand-cone test is **sand calibration**.

The sand that you use in the sand-cone test must be clean, dry, and free-flowing with a constant moisture

content while the test is performed. Uniformly graded and well-rounded sand passing the No. 20 sieve and retained on the No. 40 sieve is most suitable for the test. Almost no material finer than the No. 200 sieve should be in the sand. This sand is usually purchased in bulk quantities that can be used for many sand-cone tests performed over extended lengths of time. The density of the sand may be determined soon after the sand is received; however, since the bulk density of the sand is affected by changes in temperature and humidity, you must recalibrate the sand before each test.

To calibrate (or recalibrate) the sand, you first weigh the assembled apparatus when it is empty, clean, and dry. This weight is recorded on line 2 of DD Form 1215 (fig. 13-6A). Next, the apparatus is filled with air-dried sand by pouring the sand into the apparatus through the large end of the cone. When the jar and lower end of the cone is filled and all excess sand is removed, weigh the sand-filled apparatus. Record that weight on line 1. Then by subtracting these weights, you can determine the weight of the sand (in grams). Finally, to determine the calibrated density of the sand, you convert the weight of the sand to pounds and divide by the volume of the apparatus.

UNIT WEIGHT DETERMINATION "VOLUME OF HOLE" METHODS		DATE 2 APR 1994	
PROJECT HIGHWAY #203	TEST SITE E STA 50+00 E STA 52+00	SAMPLE NUMBER 203-6 203-7	
ADDITIONAL SPECIFICATIONS FILL COMPACTION			
CONVERSION FACTORS 1 in. = 2.54 cm. 1 gm./cc. or 62.4 lb./cu. ft. = Unit weight of water 1 lb. = 453.6 gm. 1 cu. ft. = 1728 cu. in.			
CALIBRATION OF STANDARD MATERIAL		STANDARD MATERIAL (Check one) <input checked="" type="checkbox"/> SAND <input type="checkbox"/> OIL <input type="checkbox"/> OTHER (Specify)	
APPARATUS OR TARE NUMBER		UNITS	
1. WEIGHT OF APPARATUS OR TARE FILLED		gm	12530
2. WEIGHT OF APPARATUS OR TARE EMPTY		gm	3711
3. WEIGHT OF MATERIAL (1. - 2.)		gm	8819
4. VOLUME OF APPARATUS OR TARE		cu. ft.	.2048
5. UNIT WEIGHT OF MATERIAL ($\frac{3.}{4.}$)		lb./cu. ft.	94.9
6. AVERAGE UNIT WEIGHT OF MATERIAL		LB / CU. FT.	
CALIBRATION OF APPARATUS		TEMPLATE NUMBER 203-6 203-7	CONE NUMBER
7. INITIAL WEIGHT OF APPARATUS + SAND		gm	12530
8. FINAL WEIGHT OF APPARATUS + SAND		gm	10931
9. WEIGHT OF SAND IN TEMPLATE AND/OR CONE		gm	1599
"VOLUME OF HOLE"			
10. INITIAL WEIGHT OF APPARATUS + MATERIAL		gm	10931
11. FINAL WEIGHT OF APPARATUS + MATERIAL		gm	6608
12. WEIGHT OF MATERIAL RELEASED (10. - 11.)		gm	4323
13. WEIGHT OF MATERIAL IN HOLE (For oil, same as 12. For sand, 12. - 9.)		gm	2724
14. VOLUME OF HOLE ($\frac{13.}{6.}$)		cu. ft.	.0632

DD Form 1215, AUG 57

Figure 13-6A.—Data sheet (DD Form 1215) for in-place soil density, sand-cone method.

An alternate method of sand calibration uses a container of known weight, such as a Proctor mold. In this method, you first weigh the mold and the attached base plate. Then, after attaching the mold collar, you pour the sand through the sand cone into the mold. Next, you remove the collar, strike off the excess sand, brush off the outside of the mold and base plate, and weigh the sand-filled mold (with the base plate attached). The difference in weights (filled and empty) divided by the known volume of the mold is equal to the density of the sand.

The third calibration (**surface calibration**) is discussed as part of the site preparation since it must be performed at the test site.

SITE PREPARATION.— Site preparation consists of preparing the test surface, seating the template tray, and surface calibration of the tray.

Begin your site preparation by choosing an area of the compacted surface that appears most level. You may have to remove some loose debris; however, make no attempt to pack or smooth the surface. Next, you seat the template tray flush on the surface, especially around the center hole. If necessary, seal any spaces around the center hole of the tray with modeling clay. Then force nails through the holes in the tray to hold it firmly in place. Now you are ready to perform the surface calibration.

Surface calibration accounts for surface irregularities of the area to be tested. With the valve closed, turn the sand-filled apparatus over and place the large cone over the center hole of the template tray. Open the valve and allow the sand to pass through until the large cone is completely filled. Do NOT shake or vibrate the apparatus. Then close the valve, weigh the apparatus with the remaining sand, and enter this weight on line 8 of DD Form 1215 (fig. 13-6A). The difference between the initial weight (line 7) and the final weight (line 8) is the weight of the sand that passed through the cone valve into the lower cone and the center hole of the template. Enter that weight on line 9.

After performing the surface calibration, recover as much of the sand from the tray as possible without disturbing the template tray or the soil in the hole. Brush the remaining sand particles lightly from within the tray. Leave the template in place for the volume-of-hole determination to be discussed next.

VOLUME-OF-HOLE DETERMINATION.—

The volume-of-hole determination consists of digging out a soil sample through the center of the template and computing the volume of the resulting hole.

The hole that is dug through the center hole of the template tray should be about 6 inches deep and approximately the same diameter as the hole in the tray. When digging, keep the inside of the hole as free from pockets and sharp protuberances as possible. Make sure that **ALL** material removed from the hole is placed in a container of known and recorded weight (line 23, fig. 13-6B). Keep the lid on the container as much as possible to prevent excessive moisture loss until it is weighed. When all removed material has been placed in that container, immediately weigh it and record the weight of the container and the material on line 15. Mark the container for later identification when the soil moisture content is determined.

Next, place the sand-cone apparatus over the hole in the tray and open the valve to allow the sand to flow into the hole that you have just dug. When the sand stops flowing, close the valve and weigh the apparatus with its remaining sand. Record this weight on line 11 (fig. 13-6A). The weight of the sand required to fill the hole and the volume of the hole can then be determined by following the instructions printed on the data sheet.

DENSITY DETERMINATION.— Now that you have determined the volume of the hole, the only remaining requirements are to determine the moisture content and the dry density of the sample that was removed from the hole. The moisture content should be determined using the oven-dried method that you studied in the EA3 TRAMAN. Lines 15 through 21 of DD Form 1215 (fig. 13-6B) are used to record the moisture-content data.

The wet density or unit weight (line 25) is computed by dividing the wet soil weight (line 24) by 453.6 to convert the grams to pounds and then by the volume of the hole (line 14, fig. 13-6A). The dry density or unit weight is then computed using the formula shown on line 26 of DD Form 1215.

Nuclear Moisture-Density Meter Method

Another method for determining the moisture content and density of in-place soil uses a nuclear

WATER CONTENT DETERMINATION					
		203-6		203-7	
TARE NUMBER	UNITS				
		12		15	
15. WEIGHT WET SOIL & TARE	gm	4340		4170	
16. WEIGHT DRY SOIL & TARE	gm	4152		3995	
17. WEIGHT WATER (15.-16.)	gm	188		175	
18. WEIGHT TARE	gm	276		273	
19. WEIGHT DRY SOIL (16.-18.)	gm	3886		3722	
20. WATER CONTENT ($\frac{17.}{19.} \times 100$)	%	4.9		4.7	
21. AVERAGE WATER CONTENT	PERCENT	4.9		4.7	

UNIT WEIGHT DETERMINATION					
		203-6		203-7	
TARE NUMBER	UNITS				
		12		15	
22. WEIGHT WET SOIL & TARE	gm	4340		4170	
23. WEIGHT TARE	gm	276		273	
24. WEIGHT WET SOIL (22.-23.)	gm	4064		3897	
25. WET UNIT WEIGHT (24./14.)	LB./CU. FT.	142.0		139.8	
26. DRY UNIT WEIGHT ($25. \times \frac{100}{100 + 21.}$)	LB./CU. FT.	135.1		133.7	

REMARKS

SPEC. DRY DENSITY 132 LB/CU FT

TESTS O.K.

L. Thomas

TECHNICIAN (Signature) <i>Paul Massion</i>	COMPUTED BY (Signature) <i>Paul Massion</i>	CHECKED BY (Signature) <i>L. Thomas</i>
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DD Form 1215 Reverse, AUG 57

Figure 13-6B.—Reverse of data sheet (DD Form 1215) for sand-cone method.

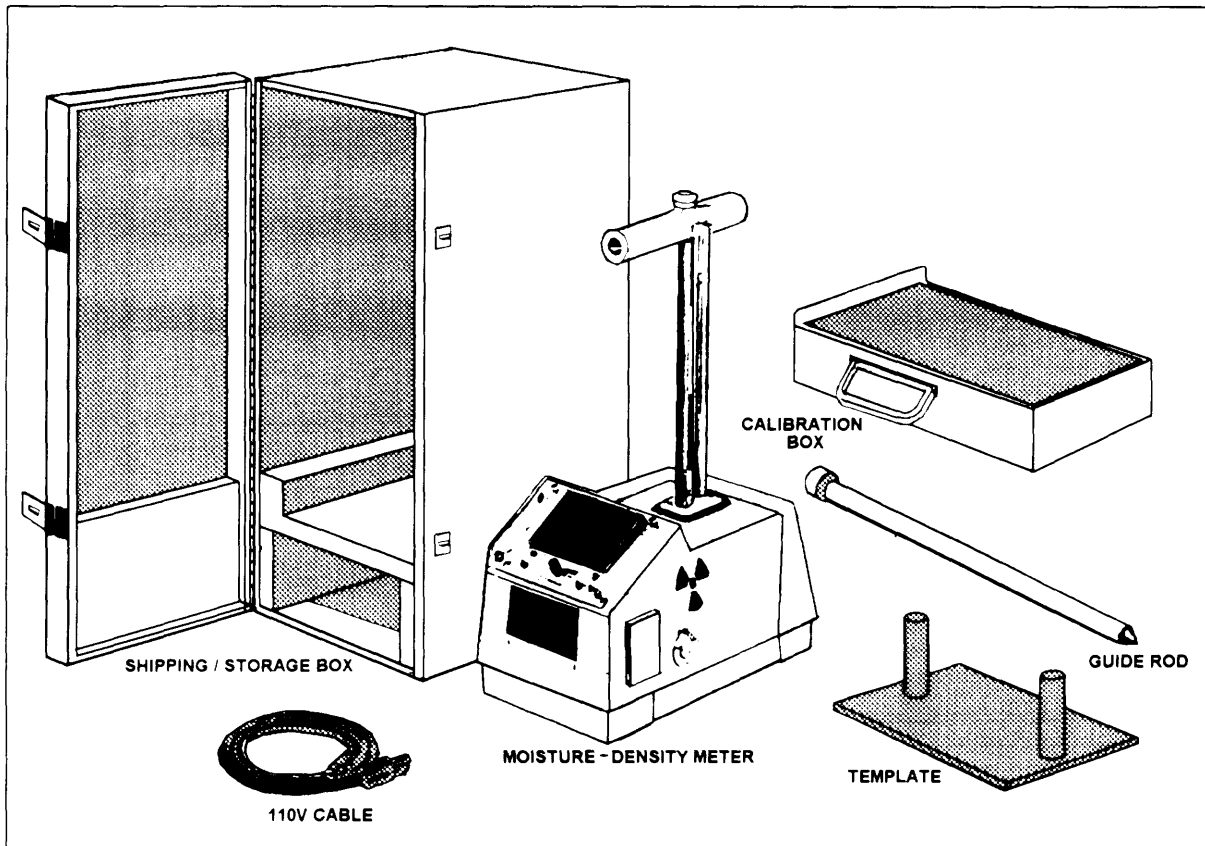


Figure 13-7.—Nuclear moisture-density meter.

moisture-density meter, such as the one illustrated in figure 13-7.

The meter contains sealed radioactive materials, typically cesium and a combination of americium mixed with beryllium powder. The cesium emits gamma radiation that the detector in the meter can count when it is passed through the soil. This count can be translated to density. The americium, interacting with the beryllium, emits neutrons following collision with hydrogen that are moderated and detected by the meter. The moisture content can be determined by measuring the hydrogen concentration in the soil.

When you are using the moisture-density meter, counts or readings are obtained and used with a calibration chart to determine the wet density and moisture content. The dry density is computed from the wet density.

CAUTION

Before using the nuclear moisture-density meter, you must complete specialized training

and receive certification through the Naval Construction Training Center at either Gulfport, Mississippi, or Port Hueneme, California.

BEARING TESTS

The bearing capacity of a soil is expressed in terms of shear resistance, which means the capacity of the load-bearing portion of a material or member to resist displacement in the direction of the force exerted by the load.

There are various types of load-bearing tests. For description purposes we will briefly discuss the **California bearing ratio (CBR) test**.

The **California bearing ratio** is a measure of the shearing resistance of a soil under carefully controlled conditions of density and moisture. The CBR is determined by a penetration shear test and is used with empirical curves for designing flexible pavements.

The test procedure used to determine the CBR consists of two principal steps. First, the soil test

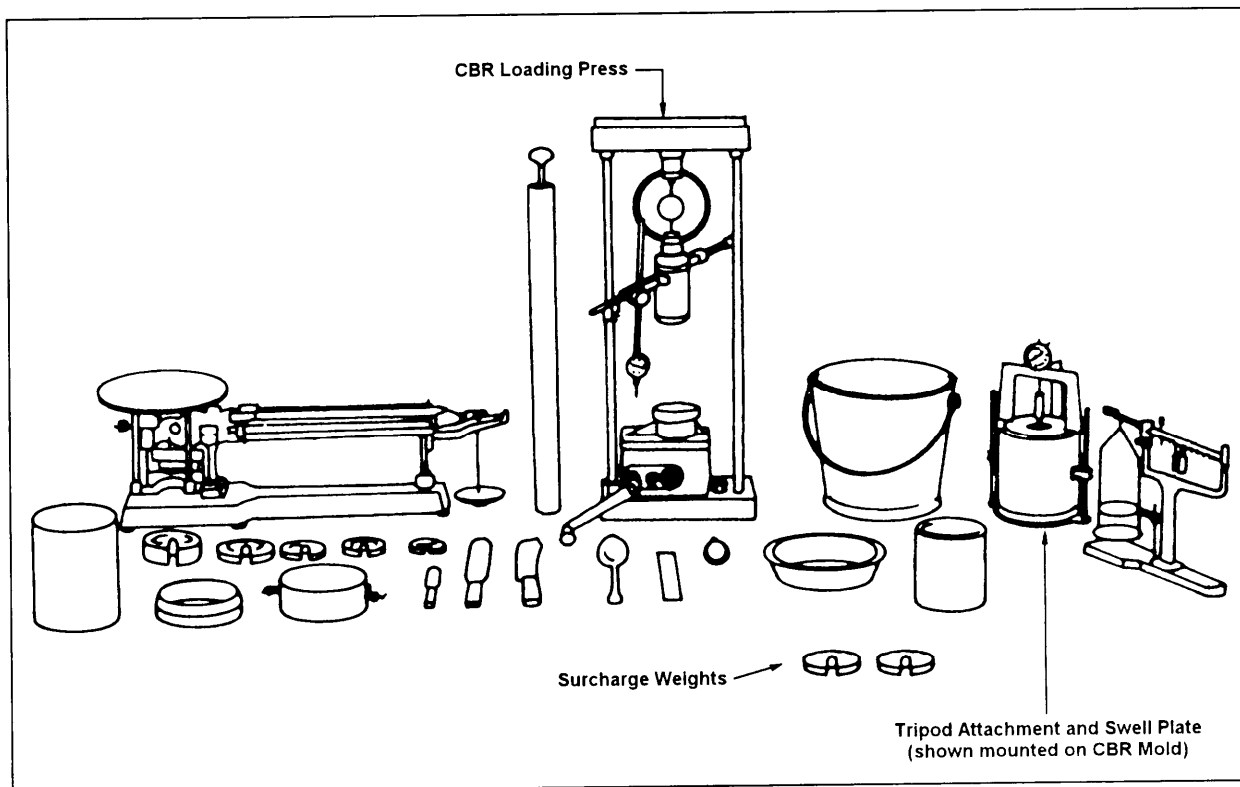


Figure 13-8.—Laboratory CBR test equipment and tools.

specimens are prepared; second, a penetration test is performed upon the prepared soil samples. Although one standardized procedure has been established for the penetration portion of the test, it is not possible to establish one procedure for the preparation of test specimens since soil conditions and construction methods vary widely. The soil test specimens are prepared to duplicate the soil conditions existing (or expected to occur later) in the field. Although penetration tests are most frequently performed on laboratory-compacted test specimens, they may also be performed upon undisturbed soil samples or in the field upon the soil in place. Detailed procedures for preparing the test samples and performing the test can be found in NAVFAC MO-330.

CBR Test Equipment and Tools

Figure 13-8 illustrates the equipment and tools needed to perform the CBR test. The principal piece of equipment is the CBR loading press. It is used to force the penetration piston into the compacted CBR specimen. The complete loading-press assembly (fig. 13-9) includes a penetration piston, proving ring and proving-ring dial, penetration dial, and a mechanical (or

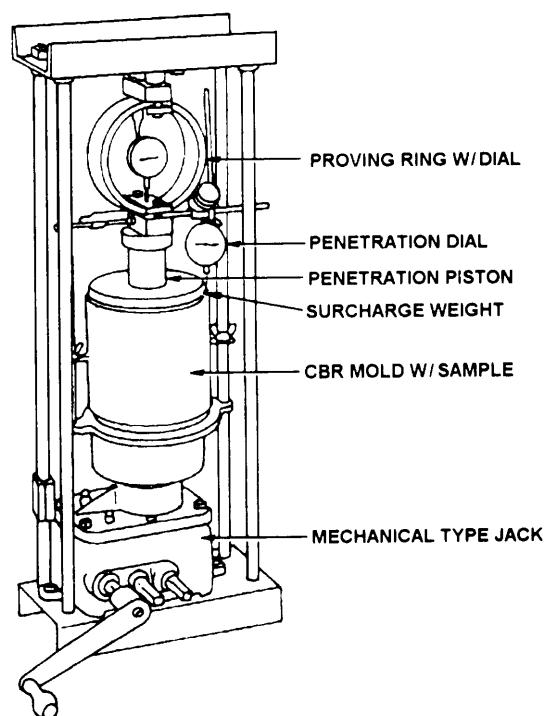


Figure 13-9.—Assembled CBR loading press.

motorized) type of jack. Three proving rings are available with capacities of 2,000, 5,000, and 7,000 pounds, respectively. The surcharge weights are used to approximate (within ± 5 pounds) the expected weight of the pavement and base in the field. The tripod attachment (when fitted with a dial indicator) and the swell plate are used to measure the expansion, or swell, of the material in the CBR mold. Other items needed to perform the test are equipment and tools, such as a balance or scale, a CBR mold, a 10-pound tamper, mixing bowls, spoons, spatulas, a soaking tank or bucket, and moisture canisters.

Preparation of Test Samples

When a bearing-ratio test is made of a compacted sample, you will use the 6-inch-diameter CBR mold with a 2 1/2-inch spacer disk in the mold beneath the sample. The use of the spacer reduces the depth of the sample to 4 1/2 inches. The use of another size spacer will result in volume and compactive effort changes that may not meet ASTM or other recognized standards for the CBR test.

The method of preparing the test specimens and the number of specimens depend upon such factors as the type of airfield or road and the soils encountered at the site. The soil sample should be tested in the laboratory at a density comparable to the density required at the construction site. There are situations where moisture conditions are favorable and the subgrade will not accumulate moisture approaching a saturated condition. In these cases, samples should be tested at a moisture content that approximates actual moisture conditions expected during the time the road or airfield is used. In all other conditions, the samples are laboratory tested in a saturated condition.

The saturated condition is attained by soaking the sample. First, place the sample in the mold and compact it. The compactive effort used and the number of compacted samples required depend upon the soil type, weight and type of field compaction equipment, and other job conditions. Normally, compactive efforts of 12, 26, and 55 blows per layer (for five layers) are used in each of three successive compaction tests. The 10-pound tamper is used for compacting the samples. After compacting the sample, trim it and remove the base plate and spacer disk. Then place a piece of filter paper over the trimmed or struck-off top of the sample and place the base plate over this top. Turn the mold over and set it in a bucket on the base plate. The bottom of the sample, which was next to the spacer disk during compaction, is now uppermost. Apply the appropriate

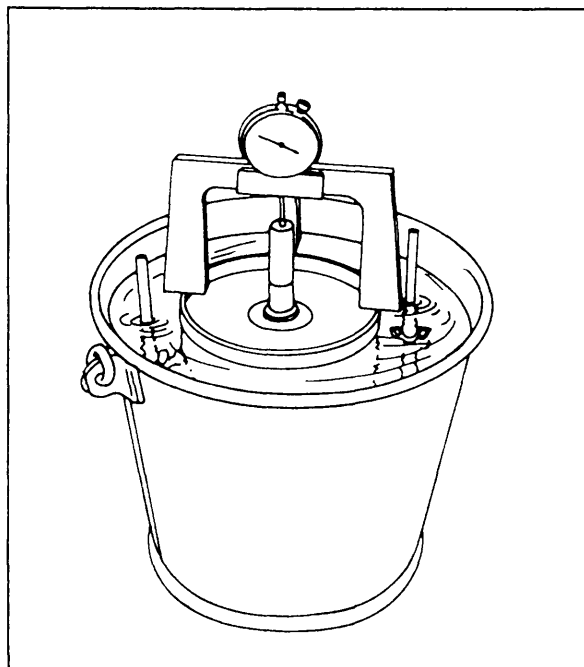


Figure 13-10.—Apparatus for soaking a CBR test sample.

number of surcharge weights needed to approximate the expected in-place weight of the pavement and base. One 5-pound surcharge weight is equivalent to 3 inches of overlying material. Then set in place the tripod attachment, dial, and swell plate, as shown in figure 13-10.

Immerse the mold and the sample in water in the bucket and leave them to soak for about 4 days. An initial reading of the tripod dial is made when the sample is first placed in the water. Then, at the end of the soaking period, the dial is read again to determine the amount of swell. A swell in excess of 3 percent of the initial height of the specimen is considered to be excessive. After making the final reading of the dial, you remove the sample and mold from the water and allow them to drain for about 15 minutes before conducting the penetration test.

Penetration Test

In the penetration test, the bearing capacity of a soil is determined by measuring the extent to which the sample, placed in a mold, is penetrated by a penetration piston. The sample (in the CBR mold) is placed in the loading press, as shown in figure 13-9. The piston is placed on top of the material, and a proving ring is placed between the top of the piston and the top of the loading press.

As the jack is cranked upward, the dial in the center of the proving ring records the pressure being applied to

CALIFORNIA BEARING RATIO TEST DATA						DATE 2 APR 1994	
PROJECT FRANKLIN AIRFIELD							
FIELD--N-PLACE		TEST SITE RUNWAY R-2					
LABORATORY		EXCAVATION NUMBER 2	SAMPLE NUMBER SF-PI-4	TYPE <input type="checkbox"/> UNSOAKED <input type="checkbox"/> SOAKED <input checked="" type="checkbox"/> DRAINED <input type="checkbox"/> UNDRAINED			
CONDITION <input type="checkbox"/> UNDISTURBED <input checked="" type="checkbox"/> DISTURBED		NUMBER OF LAYERS 5	NUMBER OF BLOWS PER LAYER 55	WEIGHT OF HAMMER (lb.) 10	DROP (inches) 18		
MOLD NUMBER 7	MOLD DIAMETER (in.) 6	MOLD HEIGHT (in.) 7	DEPTH, TOP TO SAMPLE (in.) 2.5	SAMPLE HEIGHT (in.) 4.5	SAMPLE VOLUME (cu. ft.) .073		
PROVING RING NUMBER 3		PROVING RING CONSTANT 12 LB/0.0001"	PROVING RING CAPACITY 5000 LB.	SURCHARGE WEIGHTS			
				SOAKING (lb.) 25	PENETRATING (lb.) 25		
FORMULAS Total Load = Corrected Dial Reading x Proving Ring Constant Unit Load = $\frac{\text{Total Load}}{3}$ CBR (%) = $\frac{\text{Corrected Unit Load}}{\text{Standard Unit Load}} \times 100$				CONVERSION FACTORS 1728 cu. in. per cu. ft. 453.6 gm. per lb.			
PENETRATION DATA							
PENETRATION (inches)	STD. UNIT LOAD (psi)	PROVING RING DIAL READING	CORRECTED RING DIAL READING	TOTAL LOAD (pounds)	UNIT LOAD (psi)	CORRECTED UNIT LOAD (psi)	CBR (%)
0.025	250	0.0068	0.0038	456	152	NO	
0.050	500	0.0105	0.0075	900	300	CORRECTION	
0.075	750	0.0141	0.0111	1332	444	NECESSARY	
0.100	1000	0.0170	0.0140	1680	560		56
0.150	1250	0.0210	0.0180	2160	720		
0.200	1500	0.0267	0.0235	2820	940		62.7
0.250	1700	0.0297	0.0267	3210	1070		
0.300	1900	0.0324	0.0294	3525	1175		
0.400	2300	0.0351	0.0321	3855	1285		
0.500	2600	0.0370	0.0340	3960	1320		
WATER CONTENT AND UNIT WEIGHT DATA							
WEIGHT OF SOIL - MOLD (lb.) (gm.)		15.67		OPTIMUM MOISTURE CONTENT OF SOIL, w _{opt} (%)		THEORETICAL MAXIMUM UNIT WEIGHT (Density) (lb.) (cu. ft.)	
WEIGHT OF MOLD (lb.) (gm.)		5.38		11.2		127.2	
WEIGHT OF WET SOIL (lb.) (gm.)		9.92					
VOLUME OF SAMPLE (cu. ft.)		0.073					
WET UNIT WEIGHT (lb. cu. ft.)		136.0					
TARE NUMBER				ACTUAL WATER CONTENT OF SOIL, w (%)		ACTUAL UNIT WEIGHT (lb. cu. ft.)	
WEIGHT OF WET SOIL - TARE (gm.)		143.8 164.0		8.6		99.7	
WEIGHT OF DRY SOIL - TARE (gm.)		131.5 150.3					
WEIGHT OF WATER, W _w (gm.)		12.3 13.7					
WEIGHT OF TARE (gm.)		50.2 60.7					
WEIGHT OF DRY SOIL, W _s (gm.)		81.3 89.6		DIFFERENCE (%)		PERCENT OF MAXIMUM	
WATER CONTENT, w (%)		15.1 15.3		2.6		$\frac{\text{Actual}}{\text{Maximum}} \times 100$ $\frac{99.7}{127.2} \times 100 = 78\%$	
AVERAGE w (%)		15.2					
DRY UNIT WEIGHT (Density) (lb. cu. ft.)		118.0					
REMARKS							
*Strike out unit weight not applicable. USE REVERSE SIDE FOR SWELL DATA AND GRAPH							

DD Form 1212, AUG 57

Figure 13-11A.—Front of data sheet (DD Form 1212) for California bearing ratio test.

the piston. The penetration dial (fig. 13-9) measures the extent to which the piston penetrates the material in the CBR mold.

To better understand the test procedure, let's study figure 13-11A. This figure shows an example of the data for a CBR test. In this example, figure 13-11A indicates that the sample was compacted in five layers with the

10-pound tamper, 55 blows per layer. A surcharge weight of 25 pounds is listed. That means that a 6-inch-diameter circular section of, in this case, the surface and base course of the airfield pavement is expected to weigh 25 pounds. As previously described, this weight was simulated using surcharge weights totaling 25 pounds.

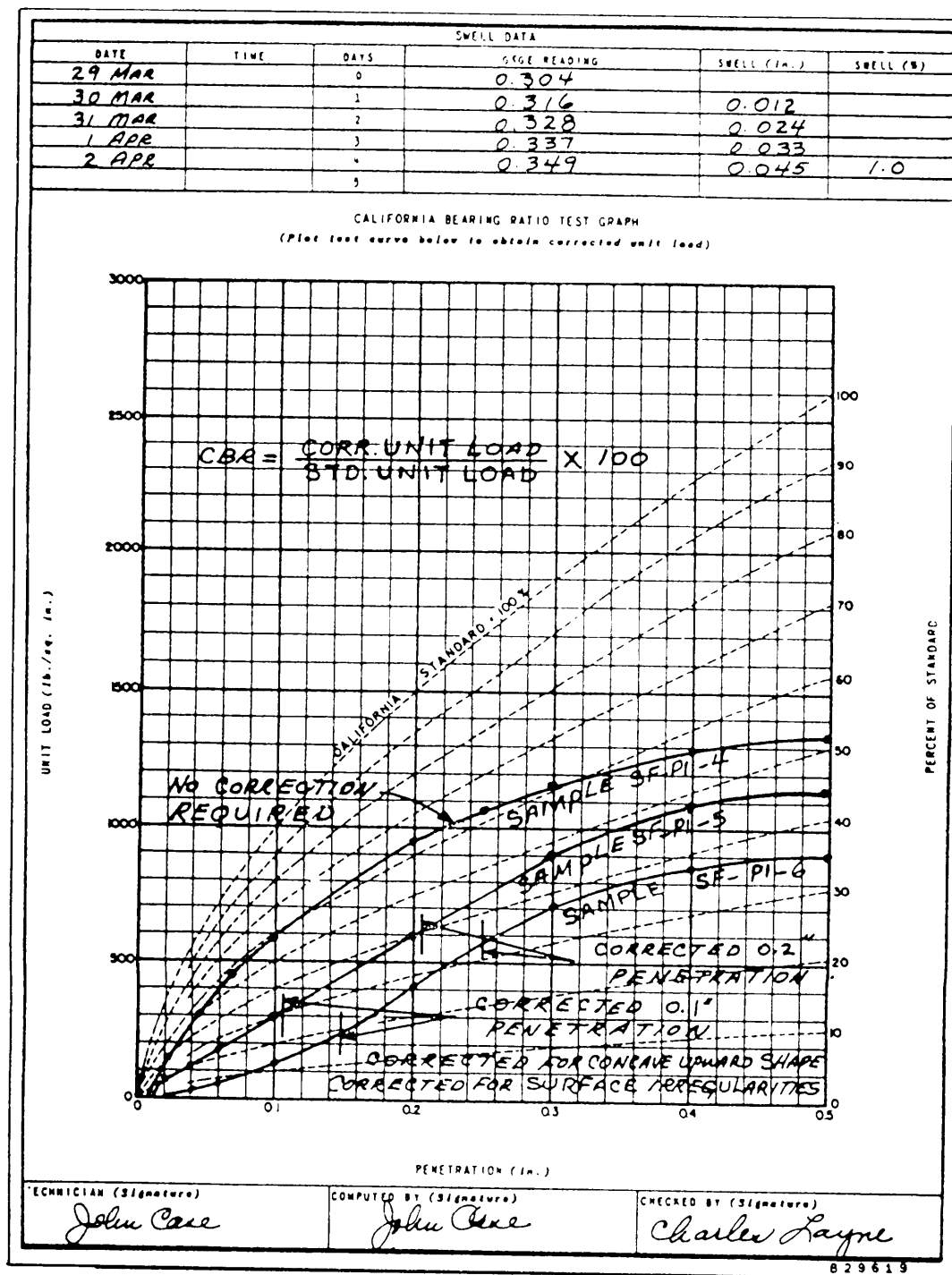


Figure 13-11B.—Stress-penetration curves (reverse of CBR test data sheet DD Form 1212).

The 5,000-pound proving ring was used for which the proving-ring constant was 12 pounds for every 0.0001 read on the proving-ring dial; for example, when the proving-ring dial reads 0.0111, the force being exerted by the piston is 12 x 111, or 1,332 pounds.

In the penetration data portion of the data sheet, you see that the first column lists standard penetrations

starting at 0.025 inch and increasing to 0.500 inch. The second column lists standard unit loads. The test was carried out by cranking the jack until the penetration dial reaches the standard penetration, then reading the load for that penetration on the proving-ring dial. Notice that for each dial reading there is a corrected dial reading that is 0.003 inch less than the uncorrected reading. This

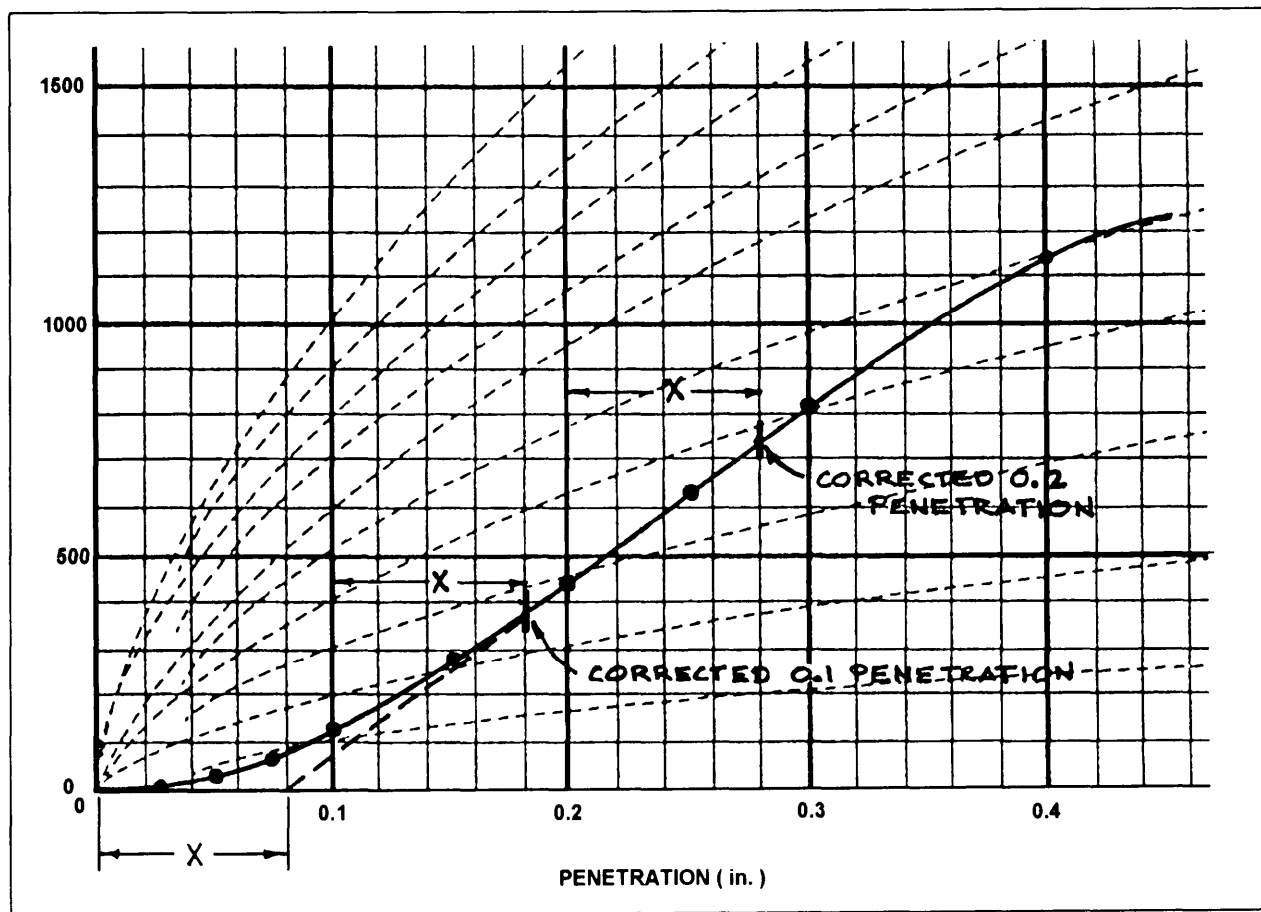


Figure 13-12.—Adjusting the zero point of the curve.

indicates that the proving-ring dial used for this test contained a previously determined index error of 0.003 inch. An error of this kind develops as a result of repeated compressions of the proving ring during testing.

The figures under **total load** are the results obtained by multiplying the corrected dial reading by the proving-ring constant. Each **unit load** was obtained by dividing the total load by 3.

Figure 13-11B is the reverse side of the CBR test data sheet. This side of the data sheet is used to plot the unit loads against the penetration depths to determine if a correction to the unit load is necessary.

In figure 13-11B you see the curve for sample SF-PI-4 that we have been discussing. The convex shape of this curve indicates that no corrections were necessary. Sometimes, however, surface irregularities in the soil sample or disturbances during the test will result in curves having an initially concave shape, such as shown in figure 13-11B for samples SF-PI-5 and SF-PI-6. This shape indicates that a correction is

necessary to obtain the true or corrected load. In this case, you must first adjust the zero point of the curve. Figure 13-12 illustrates the procedure you should use to adjust the zero point. First, draw a line that is tangent to the steepest portion of the concave curve and extend the tangent to the zero base line. The point of intersection of the tangent and the base line is the new zero-penetration point. The distance of the new zero point from the original zero point (distance X) is the distance that the 0.1 and 0.2 points are moved to the right to establish the corrected unit load.

Finally, let's look again at figure 13-11A and discuss how the CBR values are determined. To compute the CBR values, you divide the unit load (or corrected unit load) at 0.1 and 0.2 inch by the standard unit loads of 1,000 and 1,500 psi, respectively. Each result is then multiplied by 100 to obtain the CBR in percent. The CBR is usually selected at 0.1 inch; however, when the CBR at 0.2 inch is greater, you should first rerun the test and then if the check tests give similar results at 0.2-inch penetration, the CBR at 0.2 inch should be used.

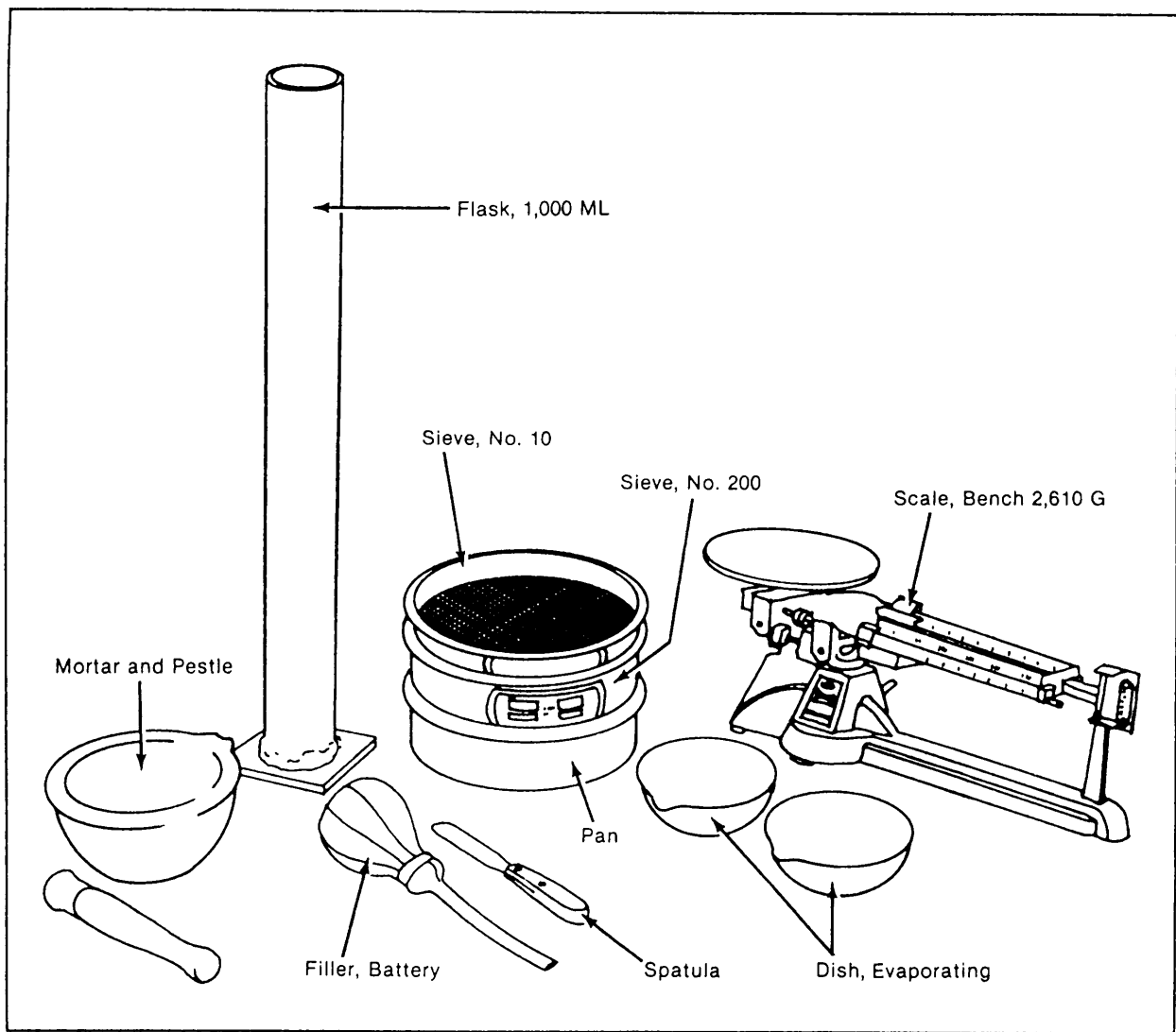


Figure 13-13.—Apparatus for grain size distribution by hydrometer analysis.

HYDROMETER ANALYSIS

You learned in the EA3 TRAMAN that a soil is considered susceptible to frost when it contains 3 percent or more by weight of particles smaller than 0.020 mm in diameter. To determine whether or not a soil contains an excessive amount of that size particle, you must perform a particle-size analysis of the materials passing the No. 200 (0.074-mm) sieve. You do this by hydrometer analysis. This TRAMAN discussion identifies the items used for a hydrometer analysis and will briefly summarize the procedures used. For a full discussion of the procedures, you should refer to NAVFAC MO-330 or to ASTM D 422. You also should review the topic of hydrometer analysis on page 15-24 of the EA3 TRAMAN before continuing with the following discussion.

Apparatus

Figure 13-13 shows some of the items that you will need to perform a hydrometer analysis. Another item you will need is an ASTM hydrometer (fig. 13-14). ASTM hydrometers are graduated by the manufacturer to read in either specific gravity or in grams per liter and are calibrated at a standard temperature of 68°F (20°C). Other needed items are a dispersion cup and stirrer (fig. 13-15), a thermometer accurate to 1°F (0.5°C), and a clock, or watch, with a second hand.

Sample Preparation and Test Procedure

Samples for hydrometer analysis are taken from representative material finer than the No. 10 sieve. The approximate size of the sample varies according to the type of soil being tested. For clays and silty soils, you

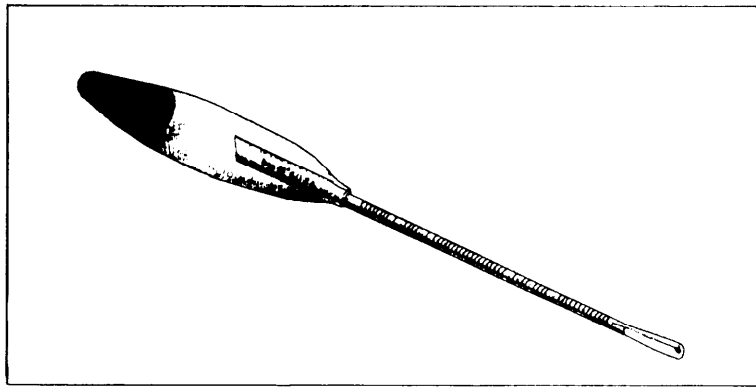


Figure 13-14.—ASTM hydrometer.

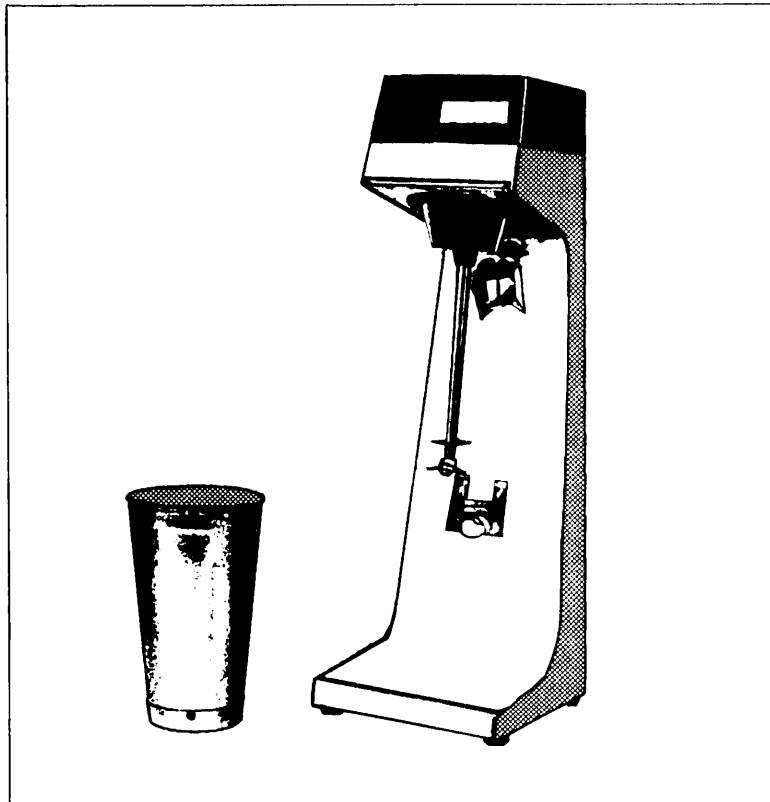


Figure 13-15.—Dispersion cup and stirrer.

will need 30 to 50 grams of air-dry material. When the sample is mostly sand, you will need approximately 75 to 100 grams.

First, place the sample in an evaporating dish. Then pour a solution of water (distilled or demineralized) and a dispersing agent, such as sodium hexametaphosphate, over the sample to make a soil-water slurry. Only enough water to submerge the sample completely and enough dispersing agent to keep the soil particles from

flocculating (adhering to each other in clusters) should be used. After it has soaked for approximately 16 hours, the soil-water slurry is transferred to the dispersion cup (fig. 13-15) and is mixed for 1 to 10 minutes depending on the plasticity of the soil.

Next, you transfer the soil-water suspension to a 1,000-milliliter (mL) sedimentation cylinder and add distilled or demineralized water to fill the cylinder to the

HYDROMETER ANALYSIS									
PROJECT <u>Helipad Proposal</u>						DATE <u>23 AUG 94</u>			
BORING NO. <u>B-1, 4</u>		SAMPLE OR SPECIMEN NO. <u>B-1, 4A</u>		CLASSIFICATION					
DISH NO. <u>1</u>		GRADUATE NO. <u>1</u>		HYDROMETER NO. <u>471252</u>					
DISPERSING AGENT USED <u>Calgon</u>						QUANTITY <u>20 ml</u>			
DISPERSING AGENT CORRECTION $C_d = 1.5$						MENISCUS CORRECTION $C_m = 0.5$			
TIME	ELAPSED TIME MIN	TEMP °C	HYDRO READING (R)	CORRECTED READING (R')	PARTICLE DIAMETER (D), mm	TEMP CORRECTION (m)	R + m	PERCENT FINER	
								PARTIAL	TOTAL
0833	0								
0834	1	19.0	60.0	60.5	.0385	-0.2	58.8	72.7	11.95
0835	2	19.0	57.0	57.5	.0280	-0.2	55.8	69.1	11.35
0837	4	19.0	52.0	52.0	.0200	-0.2	50.8	62.9	10.33
0848	15	19.5	42.0	42.5	.0130	-0.1	40.9	50.6	8.32
0903	30	20.0	33.0	33.5	.0090	0.0	32.0	39.6	6.51
0933	60	20.0	28.0	28.5	.0068	0.0	27.0	33.4	5.49
1033	120	20.5	24.0	24.5	.0048	+0.1	23.1	28.6	4.70
1233	240	22.0	20.0	20.5	.0035	+0.4	19.4	24.0	3.95
0833	1440	20.0	17.0	17.5	.0015	0.0	16.0	19.8	3.25
WEIGHT IN GRAMS		Disk plus dry soil			219.5		Specific gravity of solids, $G_s = 2.48$ Corrected hydrometer reading (R) = hydrometer reading (R') + C_d + C_m		
		Disk			138.7				
		Dry soil			W_o 80.8				
The particle diameter (D) is calculated from Stokes' equation using corrected hydrometer reading. Use nomographic chart for solution of Stokes' equation.									
<div style="display: flex; justify-content: space-between;"> <div> <p>Hydrometer graduated in specific gravity</p> $\text{Partial percent finer} = \frac{G_s}{G_s - 1} \times \frac{100}{W_o} (R + m)$ <p>Hydrometer graduated in grams per liter</p> $\text{Partial percent finer} = \frac{100}{W_o} (R + m)$ <p>Total percent finer = partial percent finer $\times \frac{W_s - W_1}{W_s}$</p> </div> <div> <p>$W_s$ = total oven-dry wt of sample used for combined analysis</p> <p>W_o = oven-dry wt in grams of soil used for hydrometer analysis</p> <p>W_1 = oven-dry wt of sample retained on No. 200 sieve</p> </div> </div>									
REMARKS <u>Frost Group = F-2</u> <u>Original sample wt. = 2045. gms</u> <u>Sample wt. retained on #200. 1799.6 gms</u>									
TECHNICIAN <u>Cummings</u>			COMPUTED BY <u>Anderson</u>			CHECKED BY <u>Gaines</u>			

DD Form 1794, FEB 71

Figure 13-16.—Data sheet for hydrometer analysis.

1,000-mL graduation. Bring the suspension to the temperature expected to prevail during the test.

Vigorously agitate the solution for 1 minute before taking and recording (fig. 13-16) your first hydrometer reading. Then, without further agitating the solution, take and record additional readings after elapsed times of 4, 15, and 30 minutes and 1, 2, 4, and 24 hours. Remove the hydrometer from the suspension after each reading and place it in a graduate of clean water.

Calculations

Readings taken with the hydrometer require correction due to the following factors: (1) the difference between the test temperature at each reading and the standard temperature of 68°F, (2) the affect of the dispersing agent on the liquid density of the soil-water suspension, and (3) the difficulty of reading the hydrometer at the meniscus of the murky soil-water

suspension. The manner in which the correction factors are determined and applied to obtain corrected readings can be found in ASTM D 422 and NAVFAC MO-330. The corrected readings are used to determine the percent passing and the particle sizes corresponding to each reading.

As you know, the larger particles in a soil-water suspension settle more rapidly than the smaller particles; therefore, for each hydrometer reading, the percent passing is the percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the soil-water suspension. That percentage, for each hydrometer reading, can be calculated using the formulas given in NAVFAC MO-330 or ASTM D 422. The particle sizes corresponding to each of those percentages is calculated on the basis of Stokes' law, that relates the terminal velocity of a free-falling sphere in a liquid to its diameter. To calculate the sizes, use the formulas given in ASTM D 422 or use the nomograph procedure discussed in NAVFAC MO-330.

CONCRETE AND CONCRETE TESTING

As you learned in the EA3 TRAMAN, concrete is one of the most economical, versatile, and universally used construction materials. It is one of the few building materials that can be produced directly on the jobsite to meet specific requirements. In this section, you will study the materials used to produce concrete and you will further your knowledge of concrete testing.

COMPOSITION

Concrete is a synthetic construction material made by mixing cement, fine aggregate, coarse aggregate, and water together in proper proportions. The following paragraphs discuss each of these materials:

Cement

Cement is a substance that hardens with time and holds or entraps objects or particles in a definite relationship to each other. For concrete, **portland cement** is usually used. Portland cement is manufactured by a standardized process consisting of grinding limestone and clay, mixing them in proportions, heating the mixture to a high temperature to form clinkers, and then pulverizing the clinkers so that 95 percent of the material will pass through a No. 200 sieve. The following paragraphs describe the various types of Portland cement:

- **TYPE I. Normal portland cement** is an all-purpose type used to make ordinary concrete pavements, buildings, bridges, masonry units, and the like.

- **TYPE II. Modified portland cement** is a type that generates less heat during the curing process than Type I. The hydration process generates heat that, in a large mass of concrete, can become high enough to affect the concrete adversely. Type II is also more sulphur-resistant than Type I. Sulphur exists in water or soil having a high alkali content and has an adverse effect on the concrete.

- **TYPE III. High-early-strength portland cement**, as the name suggests, is used where a high strength is needed quickly. That maybe due to a demand for early use, or in cold-weather construction to reduce the period of protection against low or freezing temperatures.

- **TYPE IV. Low-heat portland cement** has the heat-resistant quality of Type II, but to a higher degree. It develops strength at a slower rate than Type I but helps prevent the development of high temperatures in the structure with the attendant danger of thermal cracking upon later cooling.

- **TYPE V. Sulphate-resistant portland cement** has a higher degree of sulphate resistance than Type II and is for use where high sulphate resistance is desired.

Other types of cements maybe variations of the five types above or may be special types. Some of these types are as follows:

- **TYPE IS. Portland blast-furnace slag cement** uses granulated slag, which is rapidly chilled or quenched from its molten state in water, steam, or air. The slag (from 25 to 65 percent of the total weight of the cement) is interground with cement clinker. This cement is for general use in concrete construction.

- **TYPE IP. Pozzolan cement** uses a mixture of from 15 to 40 percent of pozzolan with the cement clinker. Pozzolan is a siliceous or siliceous and aluminous material, such as fly ash, volcanic ash, diatomaceous earth, or calcined shale. The strength of concrete made with pozzolanic cements is not as great as concrete made with the same amount of Portland cement, but its workability may be better for some uses.

- **AIR-ENTRAINED CEMENT.** Concrete made with **air-entrained cement** is resistant to severe frost action and to salts used for ice and snow removal. It is produced by adding air-releasing materials to the

clinker, as it is ground. In general, air-entrainment may be controlled to a much greater extent by the use of admixtures with normal cements during mixing. This combination results in a concrete with tiny, distributed, and separated air bubbles (up to millions per cubic foot). The entrained air bubbles improve the workability of the fresh concrete. These bubbles reduce the capillary and water channel structure within hardened concrete and restrict the passage of water. That prevents the buildup of damaging water pressure in the pores when concrete is frozen; therefore, air-entrained concrete has greatly increased durability in outdoor locations exposed to freezing weather. types I, II, III, IS, and IP cements are available as air entrained. The letter A is added after the type to signify that it is air entrained; for example, air-entrained pozzolan cement is known as Type IP-A.

In addition to the types described above, there are white cement, waterproofed cement, and oil well cement. White cement is made from selected materials to prevent coloring, staining, or darkening of finished concrete. Waterproofed cement has water-repellent materials added. The finished and set concrete has a water-repellent action. Oil well cement is specially made to harden properly when used under high temperature in deep oil wells.

Identification of Cement

The EA assigned to a construction battalion may be asked to identify unknown material received by the supply department. Every effort should be made to identify the material directly by obtaining and, if necessary, translating, all labels, tags, shipping documents, manufacturing sheets, and all other papers that may contain applicable information. When this does not produce satisfactory results, the simple procedures outlined in the following paragraphs generally will supply enough information to permit a tentative, if not conclusive, identification. The positive identification of cement, because of the wide variety of related- or similar-appearing materials, requires a complete chemical analysis and physical tests.

Make the following tests to determine whether the material is a cement, and then attempt an identification of its type.

HARDENING.— Select a small sample of the material and mix it with enough water to make a plastic paste of a consistency similar to that generally used in cement mortars. Then mold it into a pat about 3 inches in diameter and 3/4 inch thick. Observe the paste several times an hour to determine whether or not the paste is

setting (hardening). The cement has attained a final set when the surface is hard enough to be unmarked when a pencil point or a fingernail is pressed against it with moderate force. If it sets within 1 to 10 hours, the material is probably a cement.

COLOR.— If it has been fairly well established that the material in question is a cement, color may serve as a means of further classification. If the material is gray, it is likely to be a portland cement; if brownish gray, it may be a natural cement; if black, an aluminous cement; and if white, it probably is hydraulic lime, plaster, or possibly white Portland cement.

AIR-ENTRAINED CEMENT.— In the test to determine whether or not a given material contains an air-entraining agent, place a sample of the material in a glass cylinder to a depth of about 1 inch. Add water to a depth of about 6 inches and shake the cylinder and its contents vigorously. If a considerable volume of stable, persistent foam forms on the surface, the cement probably contains an air-entraining agent.

HIGH-EARLY-STRENGTH CEMENT.— A way to recognize high-early-strength cement (Type III) is to make a batch of concrete using the unknown material and at the same time a similar batch using a known cement. Concrete that contains high-early-strength cement will usually harden in less time than concrete containing regular portland cement. High-early-strength concrete, if molded into standard concrete beams and tested after 3 days for flexural strength, should have a modulus of rupture more than 150 pounds per square inch higher than similar specimens containing regular portland cement concrete. A discussion of flexural strength testing will follow later in this chapter.

Water

Water plays an important part in the concrete mix. Its principal uses are to make the mix workable and to start hydration. Any material in the water that retards or changes the hydration process is detrimental. A good rule of thumb is “if it’s good enough to drink, it may be used for concrete.”

ORDINARY WATER.— The materials found in some types of water include organic compounds, oil, alkali, or acid. Each has its effect on the hydration process. Organic material and oil tend to coat the aggregate and cement particles and to prevent the full chemical reaction and adherence. The organic material may also react with the chemicals in the cement and create a weakened cementing action, thus contributing

to deterioration and structural failure of the concrete. Alkalies, acids, and sulfates in the water tend to react with the chemicals in the cement. The result is inadequate cementing and weakened concrete. Water must be free of these chemicals to be used in concrete mixing.

SEAWATER.— The salts in seawater are normally thought of as being corrosive; however, seawater is used sometimes in concrete mixing with satisfactory results. A loss of 10 to 20 percent in compressive strength can be expected when the same amount of seawater as fresh water is used. That can be compensated somewhat by reducing the water-cement ratio.

Aggregates

The aggregates normally used for concrete are natural deposits of sand and gravel, where available. In some localities, the deposits are hard to obtain and large rocks must be crushed to form the aggregate. Crushed aggregate usually costs more to produce and will require more cement paste because of its shape. More care must be used in handling crushed aggregate to prevent poor mixtures and improper dispersion of the sizes through the finished concrete. At times, artificial aggregates, such as blast-furnace slag or specially burned clay, are used.

TYPES OF AGGREGATE.— Aggregates are divided into two types as follows:

- **FINE AGGREGATE.** “Fine aggregate” is defined as material that will pass a No. 4 sieve and will, for the most part, be retained on a No. 200 sieve. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

- **COARSE AGGREGATE.** Coarse aggregate is a material that will pass the 3-inch screen and will be retained on the No. 4 sieve. As with fine aggregate, for increased workability and economy as reflected by the use of less cement, the coarse aggregate should have a rounded shape. Even though the definition seems to limit the size of coarse aggregate, other considerations must be accounted for.

When properly proportioned and mixed with cement, these two groups yield an almost voidless stone that is strong and durable. In strength and durability, aggregate must be equal to or better than the hardened cement to withstand the designed loads and the effects of weathering.

It can be readily seen that the coarser the aggregate, the more economical the mix. Larger pieces offer less surface area of the particles than an equivalent volume of small pieces. Use of the largest permissible maximum size of coarse aggregate permits a reduction in cement and water requirements.

One restriction usually assigned to coarse aggregate is its maximum size. Larger pieces can interlock and form arches or obstructions within a concrete form. That allows the area below to become a void, or at best, to become filled with finer particles of sand and cement only. That results in either a weakened area or a cement-sand concentration that does not leave the proper proportion to coat the rest of the aggregate. The maximum size of coarse aggregate must be no larger than the sizes given in table 13-1. The capacity of the mixing equipment may also limit the maximum aggregate size.

GRADATION.— Gradation of aggregate refers to the amount of each size of particle used in the mix. Too large a proportion of coarse aggregate leaves voids that require more cement paste to fill. That affects the

Table 13-1.—Maximum Recommended Size of Coarse Aggregate

Structure	Minimum dimension—inches			
	2 1/2 - 5	6 - 11	12 - 29	30 or more
Reinforced wall, beams, and columns	1/2 - 3/4	3/4 - 1/2	1 1/2 - 3	1 1/2 - 3
Unreinforced walls	3/4	1 1/2	3	6
Slabs, heavily reinforced	3/4 - 1	1 1/2	1 1/2 - 3	1 1/2 - 3
Slabs, lightly reinforced	3/4 - 1 1/2	1 1/2 - 3	3	3 - 6
Note: Maximum size not to exceed one fifth of minimum dimension of a wall or similar structure, one third of slab thickness for horizontal slab, or three fourths of minimum clear spacing between reinforcing bars.				

economy of the mix. Too much fine aggregate, besides preventing a good bonding, also increases the surface area that must be coated with cement paste. That weakens the concrete. Good gradation results in a dense mass of concrete with a minimum volume of voids, an economical mix, and a strong structure. Optimum strength, watertightness, and durability in the hardened concrete require careful control of aggregate gradation.

DURABILITY.—Durability is the ability to resist the elements of weathering and the load pressures. Weak or easily crushed rock or other mineral particles that break down under the applied loads will cause changes in the internal stresses and a breakdown of the concrete. Rocks or mineral particles that are absorptive or susceptible to swelling when saturated will disintegrate when acted upon by different weather conditions. Freezing moisture causes expansion stresses that can easily rupture absorptive rocks. Radiant heat from the sun causes rocks to swell. If the heat is then followed by sudden cooling because of a shower and temperature drop, shrinkage and a breakdown of some rocks frequently occur. The aggregate must be chosen to withstand these forces of nature.

DETERIORATION.—Deterioration of concrete, in many cases, can be traced to the aggregate. An excessive amount of organic material in or on the aggregate prevents the cement paste from forming an adequate bond with the aggregate particles. A large percentage of clay or fine silts adhering to the aggregate may prevent the cement paste from reaching the particles. That results in a structurally weak concrete that also is susceptible to breakdown by weathering. Washing the aggregate to remove the silts, clays, and organic material prevents this problem.

CHEMICAL COMPOSITION.—Chemical composition of the aggregate is also important. Any chemical reaction between aggregate and cement in the presence of water reduces the hardening and cementing process. Any reduction in the amount of water-cement paste caused by a chemical reaction reduces the amount available to bond to the aggregate. This result is similar to one caused by an insufficient amount of cement.

Tests for Aggregates

For aggregate tests to be worthwhile, the sample secured for testing must be representative of the supply of aggregates. If possible, samples should represent the processed and ready-for-use aggregate. Sufficient samples should be taken from the processing plant discharge to represent the material in the stockpile. The

sample should contain at least four times as much material as is needed for testing and should be reduced to the size desired for testing by quartering. The standard method for sampling aggregate can be found in ASTM D 75.

Stockpile samples should be taken at or near the base, at about the middle, and at the top of the pile. Three or four such samples should be taken and recombined. A board shoved into the pile just above the point of sampling will prevent the material above the sampling point from falling or sifting into the sample.

Unprocessed sources of sand and gravel should be taken by channeling exposed faces, or they should be taken from pits if exposures are not available. Take care to ensure that the samples include only those materials that are below the overburden or strip zone.

TESTS FOR GRADATION.—A sieve analysis indicates whether an aggregate is coarse or fine and whether it is evenly or unequally distributed between the larger and smaller sizes. This information is useful in deciding whether the aggregate will make good concrete. Analysis methods can be found in ASTM C 136. Table 13-2 shows the acceptable gradation limits.

Table 13-2.—Desirable Gradation for Aggregates in Concrete

a. Coarse aggregate.

Sieve size in.	3	2½	Percent passing indicated sieve				
			No. 357	No. 457	No. 57	No. 67	No. 7
3	100						
2½	88	100					
2	76	86	100				
1½	61	69	81	100			
1	44	49	58	72	100		
¾	33	38	44	55	76	100	
½	21	24	28	35	48	63	100
¼	14	16	18	23	32	41	65
No. 4							

b. Fine aggregate.

Sieve size U.S. Standard	Percentages by weight passing
4	95–100
8*	80–100
10	75–95
16*	50–85
20	40–75
30*	25–60
40	20–50
50*	10–30
60	10–25
100	2–10

*ASTM C 33 specifies U.S. Standard sieve sizes No. 8, 16, 30, and 50 instead of No. 10, 20, 40 and 60. Both ranges are provided for convenience.

Fine aggregate grading limits are specified by the American Society for Testing and Materials; however, since many gradings of fine aggregate can produce a good quality concrete, the engineer should compute the **fineness modulus** of the aggregate and compare it to the specified concrete class requirements.

The fineness modulus is an empirical factor that gives a relative measure of the proportions of fine and coarse particles in an aggregate. It is a value widely used to indicate the relative fineness or coarseness of a fine aggregate. To obtain the fineness modulus, sieve a 500-gram sample of sand through a series of sieves (Nos. 4, 8, 16, 30, 50, and 100). Convert the weight retained on each sieve into a cumulative percentage retained, starting with the No. 4 sieve. Divide the sum of the six percentages by 100. The resulting answer is the fineness modulus. Typical fineness modulus values are as follows:

Fine sand = 2.20 to 2.60

Medium sand = 2.60 to 2.90

Coarse sand = 2.90 to 3.20

TESTS FOR SOUNDNESS.— Soundness is the property of aggregate to resist disintegration when subjected to freezing and thawing. Two methods are used to test for soundness. In the **freeze-thaw test** method (ASTM C 666), concrete specimens, made with the aggregate in question, are placed in water and then subjected to alternate cycles of freezing and thawing. An alternate method, requiring considerably less equipment and time, is the **salt test**. This procedure involves solutions of special salts (sodium sulfate or magnesium sulfate) in which the aggregate is immersed and saturated. The crystals of these salts are permitted to grow that creates a disruptive force similar to freezing water. You can find the procedures to perform the salt test in ASTM C 88 and in NAVFAC MO-330.

TESTS FOR IMPURITIES.— The quality of aggregate is another important consideration. The presence of organic material, excessive quantities of silt or clay and shale, or other water-absorbing particles can be detrimental to the concrete strength, watertightness, and durability. Tables showing the recommended limits of deleterious materials in fine and coarse aggregate can be found in NAVFAC MO-330.

Test for Material Finer Than No. 200 Sieve.— The extremely fine mineral material (clay, silt, dust, or loam) occurring in most aggregates can affect concrete in two ways. The added surface area of the fine particles picks

up the cement paste and reduces the amount available to bind and hold the aggregate. The small particles also tend to float up to the surface when the concrete is finished (especially when wet mixes are used). That results in a surface covered by hairline cracks and a tendency for the fines to dust off when dry. For some purposes a small amount of fine material may improve workability; however, amounts in excess of 3 to 5 percent of the total weight of the aggregate are generally considered harmful to the concrete.

The specific procedures that you should follow when testing for these fine materials can be found in ASTM C 117 and in NAVFAC MO-330. Briefly, you oven-dry and weigh a sample of the aggregate. Then the dried sample is brought to suspension in water and is carefully poured through a nest of sieves (No. 16 and No. 200) until the wash water is clear. Finally, the material remaining on the sieves is oven-dried and weighed. The percent of material finer than the No. 200 sieve is then calculated using the following formula:

$$P = \frac{W_d - W_{dw}}{W_d} \times 100$$

Where:

P = Percentage of fines

w_d = original dry weight of sample

W_{dw} = dry weight after washing

The method described above is accurate, but time-consuming. When time is critical and less accurate results are acceptable, you can place a 1,000-gram sample into a quart mason jar to a depth of about 2 inches. Then fill the jar three-fourths full of water, shake the mixture vigorously, and allow it to stand for 1 hour. The silt and clay will form a layer at the top of the sand. If the layer is more than 1/8 inch thick, the material has more than 3 percent fines and should be washed before using.

Test for Clay Lumps and Friable Particles.— This test is performed on the material remaining after you determine the material finer than the No. 200 sieve. The size of samples needed and the specific test procedures that you should use are in ASTM C 142 or in NAVFAC MO-330. Spread the sample in a thin layer on the bottom of a flat pan and cover it with distilled water. After about 24 hours, you break up all particles by crushing them between the fingers. Next, you remove the broken clay lumps and friable particles by wet sieving over the appropriate one of the following sieves: aggregate—No. 20; No. 4 to 3/8 inch—No. 8; over 3/8 inch—No. 4.

Oven-dry and weigh the material retained. Then you can calculate the percentage of clay lumps and friable particles using the following equation:

$$P = \frac{W_1 - W_2}{W_1} \times 100$$

Where:

P = percent of clay lumps and friable particles

w_1 = original weight of test sample

W_2 = weight of retained sample after wet sieving and drying

Test for Undesirable Lightweight Material.—

Soft, laminated pieces of aggregate, such as chert or shale, are harmful to concrete. Coal and lignite, also, are harmful and are distinguished from the lightweight materials by the brownish black or black color of the particles. Visual examination of the coarse aggregate will often show these minerals. The amount of these minerals in an aggregate can be determined by submersing the aggregate in a liquid with a specific gravity that will allow the shale or other light particles to float and heavier particles to sink.

For specific testing procedures, you should refer to ASTM C 123 or to NAVFAC MO-330. Briefly, you perform the test by first sieving the dried sample over a No. 50 sieve for fine aggregate and a No. 4 sieve for coarse aggregate. Weigh the sample and then place it into a heavy liquid, such as zinc chloride (specific gravity of 1.95 at 78°F). Agitate the mixture to allow the lightweight particles to rise to the surface and skim them off. When repeated agitation causes no further particles to rise, you wash the sample in alcohol and then dry and weigh it. The percentage of undesirable, lightweight particles can then be calculated using the following formula:

$$L = \frac{W_1}{W_2} \times 100$$

Where:

L = percentage of lightweight material

W_1 = dry weight of lightweight material

W_2 = dry weight of initial sample retained on No. 50 sieve for fine aggregate or No. 4 sieve for coarse aggregate

Color Test for Organic Matter.— Any sand that gives a color darker than the standard of this test probably contains an excess of organic matter that will reduce the strength of the concrete in which the sand is used. If you determine that organic matter is present, it is possible that it can be removed by washing; if not, better sand should be obtained. If neither of these things can be done, it will be necessary to use a lower water-cement ratio and control the concrete production carefully to obtain the desired strength.

For the color test, you will need the items illustrated in figure 13-17. To perform the test, you add the sample being tested to a solution of sodium hydroxide and water. After allowing the sample to stand for 24 hours, you then compare the color of the liquid above the sample to a standard color solution consisting of tannic acid, alcohol, and sodium hydroxide. If the liquid above the sample is darker in color than the standard solution, the sand may contain organic impurities. NAVFAC MO-330 provides full details for preparing the solutions and performing the test.

As an alternative, the color of the liquid above the sample can be compared with the colors given in the ASTM standard color plate. Then decide whether the sand contains an excessive amount of organic matter.

SPECIFIC GRAVITY, ABSORPTION, AND SURFACE MOISTURE.— These tests must be performed on the aggregate before the necessary calculations can be made to design a concrete mixture. For aggregates used in portland cement concrete, measurements are made to determine the bulk specific gravity of the aggregates in a saturated, surface-dry (SSD) condition. Specific gravity is thus based on determining the total volume occupied by the aggregate particles, including the permeable pore space.

Absorption and surface moisture determinations are necessary to calculate the amount of mixing water used in a concrete mixture. Absorption, determined as a percentage, represents the moisture content of the aggregate when the aggregate is in a SSD condition. Surface moisture is the water that is present in both fine and coarse aggregate, exceeding that which corresponds to a SSD condition.

Concrete-mixture design is discussed at the EA1 level in Part 2 of this TRAMAN.

Specific Gravity and Absorption, Coarse Aggregate (ASTM C 127).— The summarized steps in determining the bulk specific gravity of SSD coarse

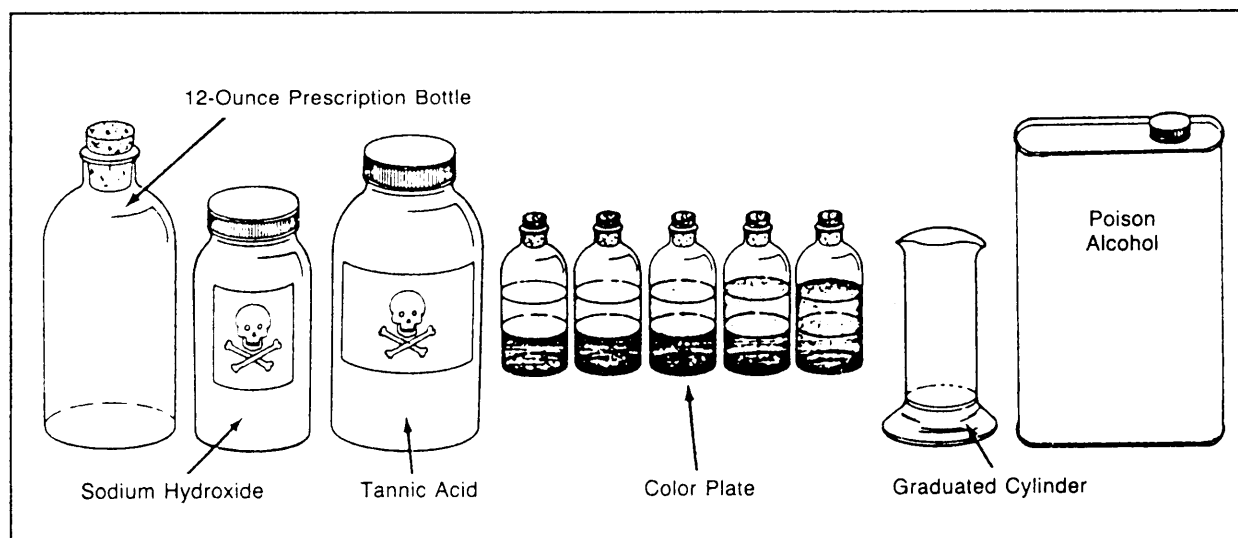


Figure 13-17.—Items required for testing sand for organic matter.

aggregate and the percentage of absorption are as follows:

1. Dry a representative sample of the aggregate (approximately 5,000 grams) to a constant weight at 110°C. Then cool the sample for 1 to 3 hours, immerse it in water, and allow it to soak for about 24 hours.

2. Remove the sample from the water and dry it to a saturated, surface-dry condition by rolling the sample in an absorbent cloth until visible films of water are removed and the particle surfaces appear slightly damp.

3. Weigh the sample in the SSD condition and record the weight to the nearest 0.5 gram. Then immediately place the sample into a container or wire basket and determine its immersed weight (or weight in water) at 23°C. Be sure that any entrapped air is removed by shaking the container or basket while it is immersed. Record the immersed weight to the nearest 0.5 gram.

4. Dry the sample to a constant weight at 110°C, cool it for 1 to 3 hours, and then weigh the oven-dried sample. Record the weight to the nearest 0.5 gram.

5. The bulk specific gravity (SSD condition) and the percentage of absorption can now be calculated using the following formulas:

$$\text{SSD bulk specific gravity} = \frac{B}{B - C}$$

And:

$$\% \text{ absorption} = \left(\frac{B - A}{A} \right) \times 100$$

Where:

A = weight of oven-dried sample in air (in grams)

B = weight of SSD sample in air (in grams)

C = immersed weight of saturated sample (in grams)

Specific Gravity and Absorption, Fine Aggregate (ASTM C 128).— The procedures for determining the bulk specific gravity of the fine aggregate in a SSD condition and the percentage of absorption are as follows:

1. Dry a representative sample of the fine aggregate (about 1,000 grams) to a constant weight at 110°C. Then cool the sample, immerse it in water, and allow it to soak for about 24 hours.

2. After the soaking is completed, spread the sample on a flat, nonabsorbent surface and stir it to obtain uniform drying. Continue drying the sample until it approaches a SSD condition.

3. Next, you place a water-absorption cone (fig. 13-18) large end down on a smooth surface and fill it loosely with the aggregate. Then lightly tamp the surface of the aggregate 25 times with the metal tamper.

4. Lift the cone vertically from the sand and observe the action of the sample. If it retains its conical shape, free moisture is present and continued drying (Step 2) followed by repeated tamping (Step 3) is required. If the sample slumps slightly, the fine aggregate has reached the desired SSD condition.

5. Weigh exactly 500 grams of the SSD sample and place it in a partially water-filled pycnometer top-and-jar assembly (fig. 13-19). Fill the jar with additional water to approximately 90 percent of its capacity.

6. Agitate the sample in the pycnometer assembly to remove any entrapped air, adjust the water temperature to 23°C, and fill the pycnometer to its calibrated capacity. Then weigh the filled pycnometer to the nearest 0.1 gram and record the weight.

7. Remove the sample from the pycnometer and dry it to a constant weight at 110°C. Then cool the sample in air for about 1 hour and weigh it. Record this weight to the nearest 0.1 gram.

8. Determine the weight of the pycnometer filled to its calibrated capacity with water at 23° + 1.7°C. Record this weight.

9. You can now calculate the specific gravity of the SSD fine aggregate and the percentage of absorption by using the following formulas:

$$SSD \text{ bulk specific gravity} = \frac{500}{B + 500 - C}$$

And:

$$\% \text{ absorption} = \left(\frac{500 - A}{A} \right) \times 100$$

Where:

A = weight of the oven-dried specimen in air (in grams)

B = weight of pycnometer filled with water (in grams)

C = weight of pycnometer, sample, and water (in grams)

Surface Moisture (ASTM C 70 and ASTM C 566).— A summary of the ASTM procedures used to determine the total moisture content and the

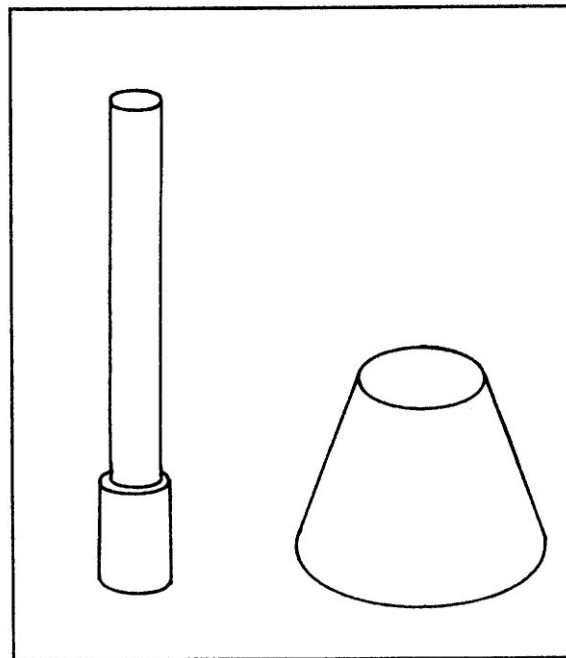


Figure 13-18.—Water-absorption cone and tamper.

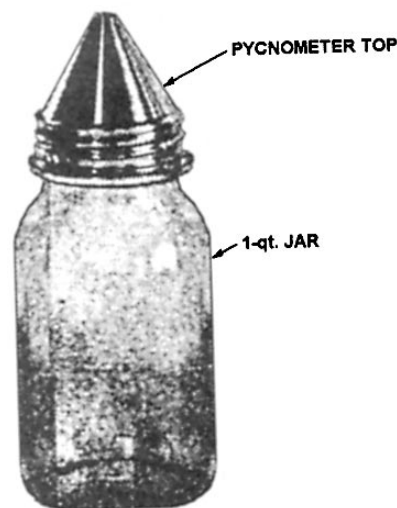


Figure 13-19.—Pycnometer top-and-jar assembly.

percentage of surface moisture in either fine or coarse aggregate are as follows:

1. Secure and weigh a sample of the aggregate that is representative of the moisture content of the material being tested.

2. Dry the sample to a constant weight at 110°C. You should take care to avoid loss of material during testing. The sample is thoroughly dry when further

heating causes, or would cause, less than 0.1 percent additional loss in weight.

3. Weigh and record the weight of the oven-dried sample.

4. Calculate the total moisture content using the following formula:

$$P = \left(\frac{W - D}{D} \right) \times 100$$

Where:

P = total moisture content (percent)

W = weight of original sample (in grams)

D = weight of oven-dried sample (in grams)

The surface moisture is equal to the difference between the total moisture content and the absorption.

An alternate determination of surface moisture in fine aggregate is obtained by displacement as follows:

1. Select a representative sample of the fine aggregate weighing not less than 200 grams.

2. Weigh a pycnometer filled to the calibration mark with water.

3. Place the sample in the pycnometer half filled with water. Add additional water to the calibration mark and remove all entrapped air. Weigh the pycnometer, water, and sample.

4. Calculate the weight of the water displaced by the sample using the following formula:

$$V_s = W_c + W_s - W$$

Where:

V_s = weight of displaced water (in grams)

W_c = weight of water-filled pycnometer (in grams)

W_s = weight of sample (in grams)

W = weight of pycnometer, water, and sample (in grams)

5. Calculate the percent of surface moisture using the following formula:

$$P = \left(\frac{V_s - V_d}{W_s - V_s} \right) \times 100$$

Where:

P = percent of surface moisture

V_s = weight of displaced water (in grams)

W_s = Weight of sample (in grams)

V_d = weight of sample in grams divided by the bulk specific gravity of the sample

ADMIXTURES

Several chemical agents, or admixtures, are available to improve workability, increase resistance to freezing and thawing, and compensate for inadequate curing time and conditions.

Accelerators

Sometimes it is desirable to accelerate the hydration reactions. The result is a high-early strength and a higher rate of heat production. This combination can be useful in winter operations. The addition of a chemical accelerator (generally calcium chloride) to the mix will produce the desired conditions. The amount specified is usually 2 percent of the weight of cement and rarely more than 3 percent. The main reaction with calcium chloride occurs within the first 3 days. The ultimate strength of concrete is not affected by the use of this chemical.

Retarders

Retarders are used when excessively high heat and too rapid setting of concrete would prevent full hydration. Many materials retard setting of concrete. Basically, these materials are types of fatty acids, starches, or sugars.

Workability Agents or Plasticizers

The workability of concrete is governed by the amount of aggregate in the mix. Where reduction of aggregate (or increase in cement) is impractical, workability is increased by adding a plasticizer. Air-entraining agents, when used, are plasticizers. Other substances include calcium chloride, lime, fly ash, and other pozzolans. Calcium chloride is also an accelerator. Lime increases the cementing properties of cement, as do pozzolans combined with lime. Fly ash is inexpensive compared to cement and is used as a partial replacement (up to as much as 50 percent) of the cement. It changes both the plastic and the hardened properties of concrete. Fly ash improves workability and reduces segregation, bleeding, and the heat of hydration. The

concrete will not be as watertight as a cement-only concrete, nor will it have as much initial strength. Additional tests may have to be made to determine when to remove the forms. Its final strength, however, will be as great as a cement-only concrete.

Densifiers

Dense concrete is required in some types of construction, such as in prestressed structures. This density is achieved when cement particles are separated evenly throughout the mix or at least prevented from attaching to each other (flocculating). A detergent admixture will disperse the particles individually and will create a more uniform paste. These admixtures also reduce the formation of a cement gel that expands at the early stages of hydration and pushes the particles apart, thus increasing the volume. Prevention of this expansion results in a denser paste.

Waterproofing Agents

Watertightness can be controlled to a great extent by lowering the water-cement ratio. This may not always be practical, and sometimes even with a low water-cement ratio, capillaries still form through the concrete. Densifying or using an accelerator like calcium chloride improves the watertightness.

Air-Entraining Agents

The greatest improvement in watertightness and resistance to deterioration under freezing and thawing is obtained by incorporating 4 to 6 percent, by volume, of entrained air into the mix. Workability of fresh concrete is enhanced by such entrained air. Air-entrained cement contains the necessary admixture. Soaps, butylstearate, some of the fine pozzolans, and several proprietary compounds are available for use as air-entraining admixtures with ordinary cements. These agents minimize the formation of capillaries and plug the tiny holes with a water-repellant or sealing material. They provide small, uniformly spaced, discrete air voids that prevent the buildup of damaging pressures from the expansion of freezing water into ice.

CURING

Concrete does not develop its full strength until the chemical process of curing (or hydration) is complete. Curing takes place over an extended period—the most critical portion of which is from the day of placement through the 10th day. The extent and rate of curing

depends upon the presence of moisture and the correct temperature within the mix.

Temperature

The ideal temperatures for concrete work are between 55°F and 70°F. Above this, rapid evaporation of moisture creates a problem. At lower temperatures, the curing or setting is delayed. Temperatures below 32°F stop the hydration process. Since the chemical action gives off some heat, some method must be used to keep the heat within the structure during times of low temperatures. Cold weather construction may even require heating the ingredients, or mix, and covering the emplaced concrete or providing a heated enclosure. In hot weather, extra care is required to prevent a high temperature rise and too rapid drying of the fresh concrete. Moistening the aggregate with cool water will lower the generated temperature. The water is kept cool as possible by the application of reflective white or aluminum paint to water supply lines and storage tanks. On massive construction, such as dams and heavy retaining walls, the mixing water is often cooled artificially or ice is substituted for part of the water. This ice must be melted by the time the concrete is fully mixed and ready to leave the mixer. Cement replacement materials (such as pozzolans of diatomaceous earth, pumicites, or fly ash) may be used to depress concrete temperature by reduction of the heat of hydration in a structure; however, pozzolans vary widely and may have adverse effects on strength, air content, and durability, if used in excessive amounts.

Moisture

Concrete curing depends upon chemical action in the presence of water. Any loss of moisture during the process by seepage or evaporation prevents complete hydration and development of optimum strength and watertightness. Saturating the subgrade on which the concrete will be placed will delay, if not prevent, seepage. Wood forms should be thoroughly wetted if they have not been treated otherwise. Covering the concrete without marring the surface as soon as possible after finishing is one method used to reduce evaporation. This covering may be some material, such as burlap, straw, or plastic film, or it may be a chemical curing compound that is sprayed over the finished surface. After the initial set is attained, water can be applied directly to the surface to keep the hydration process in action. This water application can be part of the temperature control. The increase on concrete compressive strength with age is shown by curves in

Compressive strength, per cent
of 28-day moist-cured concrete

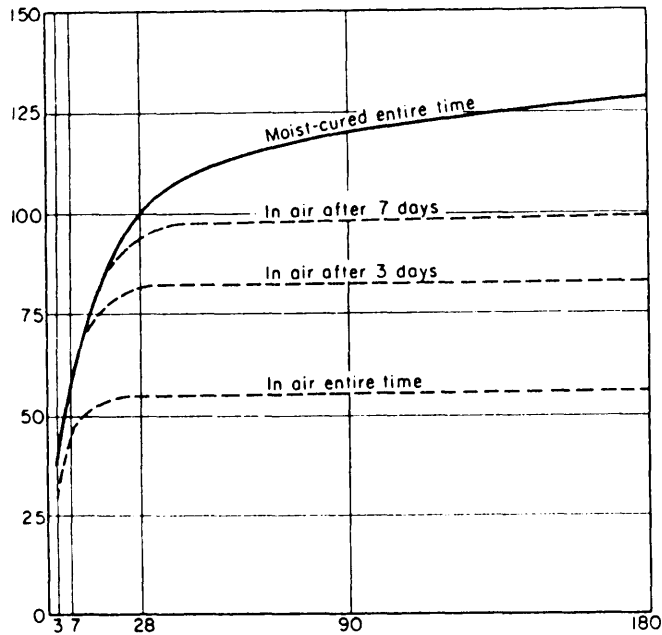


Figure 13-20.—Increase of concrete compressive strength with curing age.

figure 13-20. Note the long-time gain in strength that occurs when proper temperature and moisture conditions are maintained.

CONCRETE TESTING

Several tests, such as slump, air content, and weight determination, are necessary to determine the quality of freshly mixed concrete. In addition, strengths tests are needed to determine whether a hardened concrete satisfies specified strength requirements. This section briefly discusses those tests.

Slump Test

As you know, the measure of the workability or consistency of a concrete mix is its slump. With too little slump, the mixture may be too difficult to work into the forms and around the reinforcing steel. On the other hand, with too much slump, the concrete ingredients may segregate and excessive bleeding or migration of water to the top surface of the freshly placed concrete may occur. Excess bleeding increases the water-cement ratio near the top surface of the concrete and results in a weak top layer with poor durability.

To determine whether a freshly mixed concrete satisfies the specified requirements for slump, you must perform a slump test. By now, you should be thoroughly

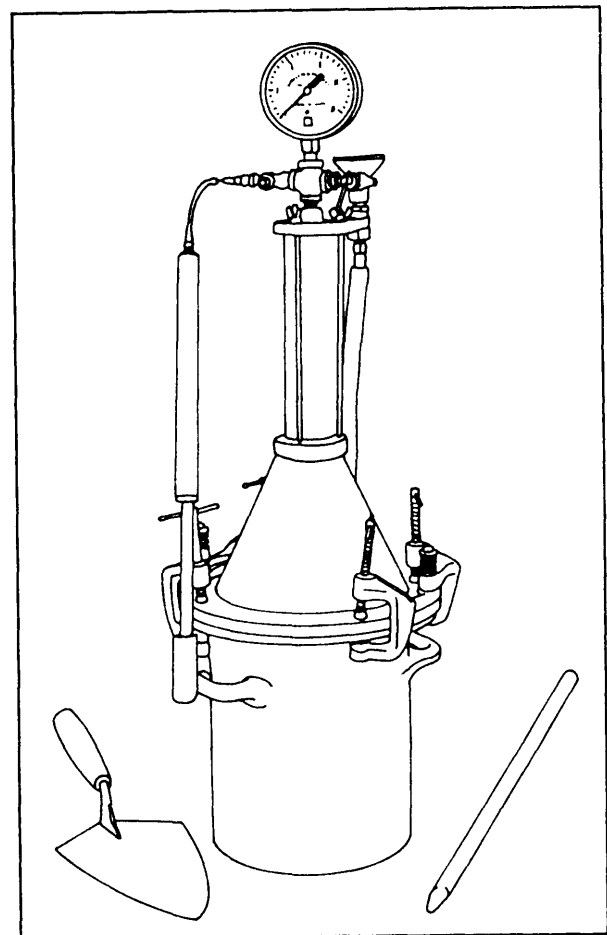


Figure 13-21.—Apparatus for air-content test.

familiar with the procedures of slump testing. If not, you should review the discussion of slump testing that is in the EA3 TRAMAN.

Air-Content Test (ASTM C 231)

An air-entraining admixture is added to the concrete mix so that enough air will be entrained to improve workability and durability of the mixture, but not enough to reduce strength substantially. Air-entraining cements may also be available for use in some military situations. The desired amount of air is generally from 4.0 to 7.5 percent of the total mix.

The equipment for determining the percentage of entrained air is included in the boxed test kit. The basic tool is the pressure type of indicator, as illustrated in figure 13-21. The equipment furnished in these kits varies with the manufacturers. Each kit contains the complete equipment for conducting the test, including a detailed instruction pamphlet and the calibration procedure for the particular meter. Before the air content of a concrete mixture can be determined, the

entrained-air indicator must be calibrated accurately, and the correction factor for the aggregate contained in the concrete must be determined.

To perform the test, follow the procedures contained in NAVFAC MO-330 and in the instruction book furnished with the meter. The instruction book also describes the calculations for determining the entrained-air content.

Unit Weight (ASTM C 138)

The unit weight, or density, of concrete varies with the amount and density of the aggregate, the amount of entrapped or entrained air, and the water and cement contents. Conventional concrete used in structures, such as buildings and pavements, has a unit weight in the range of 140 to 150 pounds per cubic foot (pcf). For other types of concrete, the unit weight ranges from 15 pcf for lightweight insulating concrete to 400 pcf for heavyweight concrete.

To determine the unit weight of freshly mixed concrete, you will need a cylindrical metal measure (container) of either 1/10-, 1/5-, or 1/2-cubic-foot capacity. If necessary, you should calibrate the measure before performing the test procedures. To calibrate the measure, you first determine the tare weight of the measure, and then fill the measure with water at room temperature. Then determine the temperature, density, and weight (in pounds) of the water. To determine the density of the water, use table 13-3 and interpolate, if necessary. Next, calculate the calibration factor of the measure by dividing the density of the water by the weight of the water required to fill the measure.

The ASTM procedures for determining the unit weight are summarized as follows:

Table 13-3.—Density of Water

Temperature		lb/ft ³
°F	°C	
60	15.6	62.366
65	18.3	62.336
70	21.1	62.301
75	23.9	62.261
80	26.7	62.216
85	29.4	62.166

1. Fill the measure with fresh concrete consolidated in three layers, as described for the air-content test. After each layer is rodded, tap the sides of the container 10 to 15 times with a rubber or rawhide mallet to remove any air pockets.

2. After filling and consolidating, strike off the top surface, taking care to leave the measure level full.

3. Clean all excess concrete from the exterior of the measure. Then weigh it and determine the net weight of the concrete inside the measure by subtracting the tare weight of the measure from the gross weight of the measure and concrete.

4. Calculate the unit weight by multiplying the net weight of the concrete by the calibration factor for the measure.

Compressive Strength Test (ASTM C 39)

The compressive strength of hardened concrete is determined from compression tests on standard cylindrical specimens. As you know, compressive strength tests are used during concrete mix design to evaluate the performance of the materials and to establish mixture proportions that will give the required strength. The tests are used also to control the quality of the concrete in the field.

“Compressive strength” is defined as the average of the strengths of all cylinders of the same age made from a sample taken from a single batch of concrete. At least two cylinders, or preferably three, are required to constitute a test. So, if tests are to be made at 7 and 28 days, you will need four or six specimens. The standard specimen is 6 inches in diameter by 12 inches long and is capped with a suitable material to provide a smooth-bearing surface on each end of the specimen. You learned the procedures for preparing and capping compressive strength specimens in the EA3 TRAMAN. If necessary, you should review those procedures. The following paragraphs discuss only the procedures used to perform compression tests on the prepared specimens.

The equipment you will use to perform the compression test is a compression-testing machine, having a capacity of 250,000 pounds. An example of that machine, shown with a test cylinder in place, is illustrated in figure 13-22.

The procedures for conducting the compression test are as follows:

1. Prepare the testing machine by cleaning the bearing plates and, if needed, cleaning and lubricating

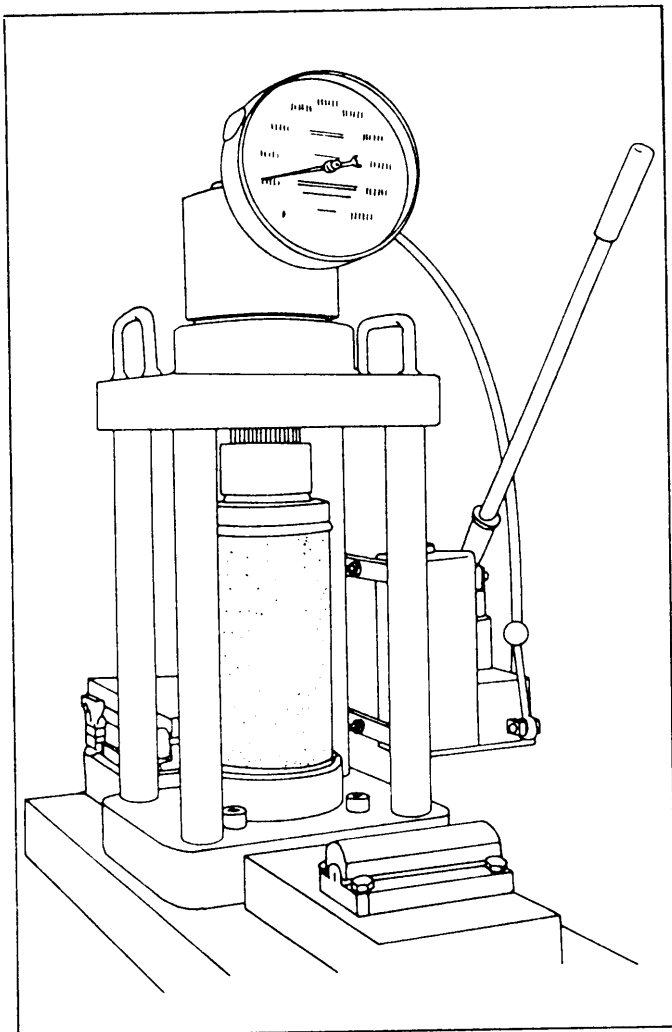


Figure 13-22.—Compression-testing machine.

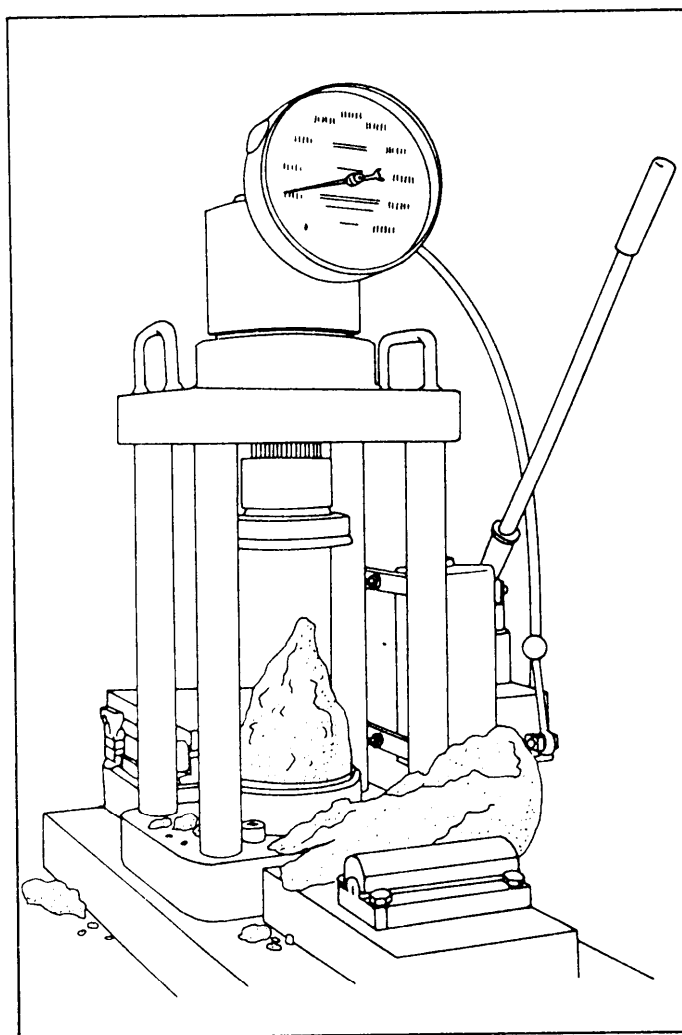


Figure 13-23.—Normal fracture of concrete test cylinder in compression.

the spherical seat. Check the operation of the machine. Keep the previously prepared test specimen moist by covering it with wet burlap during the period between removing the specimen from the curing environment and testing. That applies to each specimen you will test.

2. Determine the diameter of the test specimen to the nearest 0.01 inch by averaging two diameters measured at right angles to each other at midheight of the cylinder. Measure the length, including caps, to the nearest 0.1 inch. Record the dimensions on a prepared data sheet.

3. Place the specimen on the lower bearing block, bring the upper block almost to contact, and align the axis of the specimen with the center of thrust of the spherical head. Carefully and slowly bring the spherical head into contact with the specimen, rotating the movable portion gently by hand so that uniform seating is obtained. Apply the test load continuously and

without shock at a rate of 20 to 50 pounds per square inch (psi). Observe and record the maximum load during the test. Observe the type of fracture and record any unusual features. The normal cone type of fracture is illustrated in figure 13-23.

4. Calculate the compressive strength of the concrete using the following formula:

$$f'_c = \frac{P}{A}$$

Where:

f'_c = compressive strength (in psi)

P = maximum load (in pounds)

A = cross-sectional area of specimen (in inches)

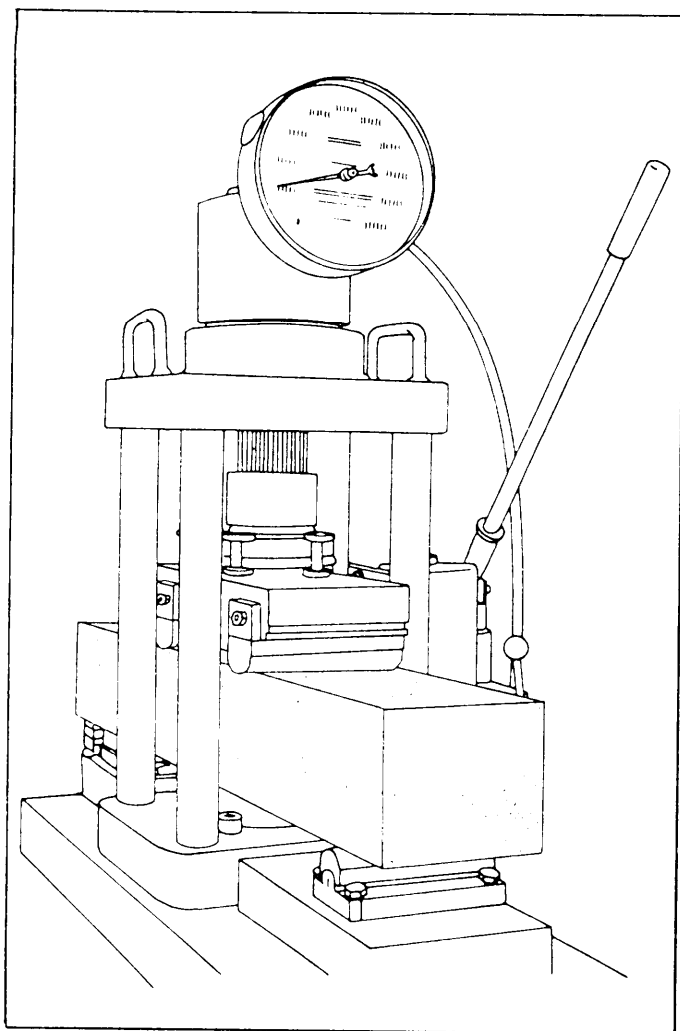


Figure 13-24.—Flexural-strength testing assembly for 6-inch by 6-inch by 21-inch concrete beam.

For each tested specimen, your test report should include the identification, diameter, length, maximum load, compressive strength, irregular fracture or defect in caps or specimen, and age of specimen at test. Report the average compressive strength of all cylinders from the same concrete sample.

Flexural-Strength Test (ASTM C 78)

Flexural strength is the ability to resist an applied bending force such as encountered by concrete pavements or other slabs on ground. A determination of the flexural strength is frequently necessary as part of the design of concrete mixtures to check compliance with established specifications or to provide information necessary to the design of an engineering structure.

In the flexural-strength test, a test load is applied to the sides of a test beam. Although the test can be performed upon beams sawed from existing concrete structures, it is more commonly performed upon beams

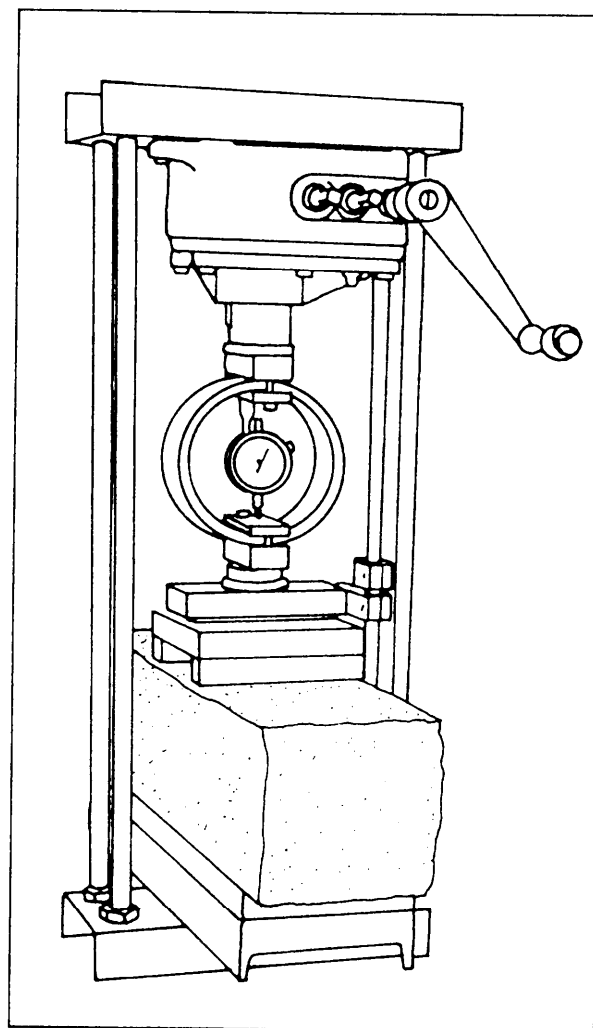


Figure 13-25.—Alternate testing assembly using CBR test equipment.

that are cast for testing purposes. The standard test beam measures 6 inches by 6 inches by 21 inches. When performing the test for mix-design purposes, you will need at least five beam specimens for each mixture design being evaluated. Two of the specimens are broken at 7 days to permit an early evaluation of the mix. The remaining beams are broken at 28 days. The procedures for preparing test beams is discussed in the EA3 TRAMAN. If necessary, you should review those procedures. The following paragraphs discuss only the procedures used to perform the test.

When performing the flexural-strength test, you use a concrete beam tester with third-point loading. An example of that equipment is illustrated in figure 13-24. An alternate testing assembly can be made from the loading frame and certain attachments provided with the California bearing ratio (CBR) test set, the breaker (third-point loading), and the 10,000-pound capacity proving ring. That alternate assembly is shown in figure 13-25.

The procedures for conducting the flexural-strength test are as follows:

1. Assemble the loading device, as shown in figure 13-24. Turn the test beam so that the finished surface is to the side and centered in the loading assembly. Operate the testing apparatus until the loading blocks are brought into contact with the upper surface of the beam. Be sure to secure full contact between the loading (and supporting) surfaces and the beam. If the surface of the specimen is so rough that full contact is not secured, grind the specimen to secure full contact.

2. Apply the test load at a rate such that the increase in extreme fiber stress in the beam is between 125 and 175 pounds per square inch per minute. The extreme fiber stress corresponding to any load maybe estimated from the equation given in Step 4a below. Obtain readings on the proving-ring dial, and convert them to corresponding total loads in pounds by applying the proving-ring constant. Aside from the reading used to control the rate of application of the load, the only reading necessary is the one that corresponds to the maximum load applied to the beam.

3. After the specimen has broken, obtain dimensions of the cross section at which failure occurred to the nearest 0.1 inch. These dimensions represent the average width and average depth of the section in failure.

4. The flexural strength, expressed in terms of **modulus of rupture**, is given in psi, and can be calculated as follows:

- a. If the specimen broke within the middle third of the span length, use the following equation:

$$R = \frac{PL}{bd^2}$$

Where:

- R = modulus of rupture (in psi)
- P = maximum applied load (in pounds)
- L = span length (in inches)
- b = average width of specimen (in inches)
- d = average depth of specimen (in inches)

- b. If the specimen broke outside the middle third of the span length by not more than 5 percent of

the span length, calculate the modulus of rupture as follows:

$$R = \frac{3Pa}{bd^2}$$

Where:

- R = modulus of rupture (in psi)
- P = maximum applied load (in pounds)
- a = distance (in inches) between the line of fracture and the nearest support, measured along the center line of the bottom surface of the beam
- b = average width of specimen (in inches)
- d = average depth of specimen (in inches)

- c. If the specimen broke outside the middle third of the span length by more than 5 percent of the span length, discard the results of the test.

5. The report of the test for flexural strength should include the following information:

- a. Identification number
- b. Average width to the nearest 0.1 inch
- c. Average depth to the nearest 0.1 inch
- d. Span length
- e. Maximum applied load
- f. Modulus of rupture to the nearest 5 psi
- g. Defects in specimen
- h. Age of specimen

Values of the modulus of rupture vary widely, depending on the concrete tested. Specification relative to concrete pavements frequently require modulus of rupture in excess of 600 to 650 psi (28-day curing, third-point loading). The flexural strength (modulus of rupture) generally may be expected to be approximately 15 percent of the compressive strength for comparable conditions of age and curing.

An approximate relationship between modulus of rupture and compressive strength can be calculated from the following formula:

$$f'_c = \frac{R^2}{100}$$

Where:

- f'_c = compressive strength (in psi)
- R = modulus of rupture (in psi).

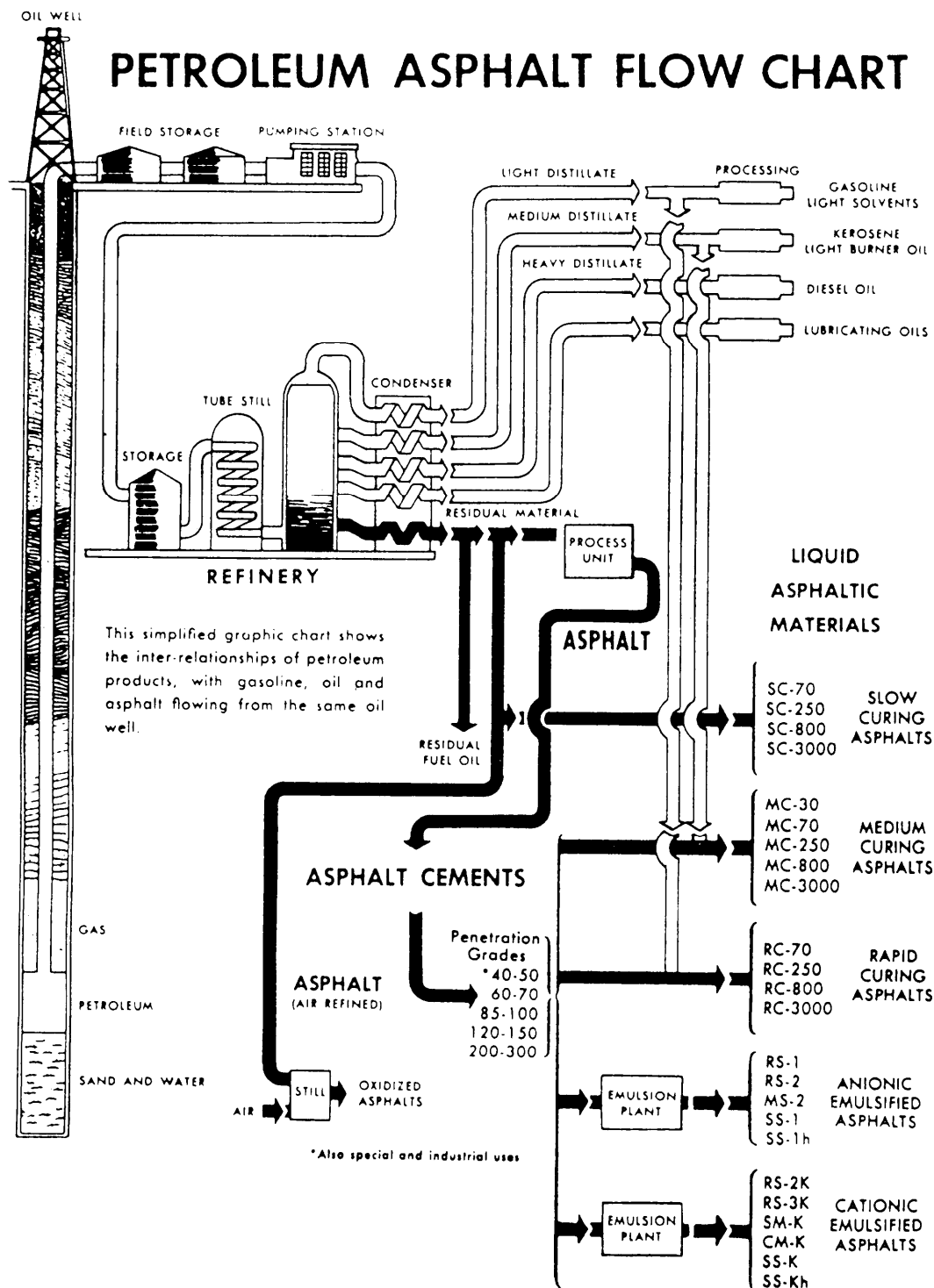


Figure 13-26.—Simplified flow chart showing recovery and refining of petroleum asphaltic materials.

Other Concrete Strength Tests

The compressive and flexural strength tests that you studied above are the two strength tests that you, as an EA, are expected to know how to perform. One should not gain the opinion, however, that those are the only ways to determine the strength of hardened concrete. Other methods, such as the rebound method (ASTM C

805) and the pullout test method (ASTM C 900), also are used.

The rebound method employs a rebound hammer that measures the rebound of a spring-loaded plunger striking a smooth concrete surface. A rebound number reading indicates the compressive strength of the concrete. In the pullout test, the enlarged end of a steel

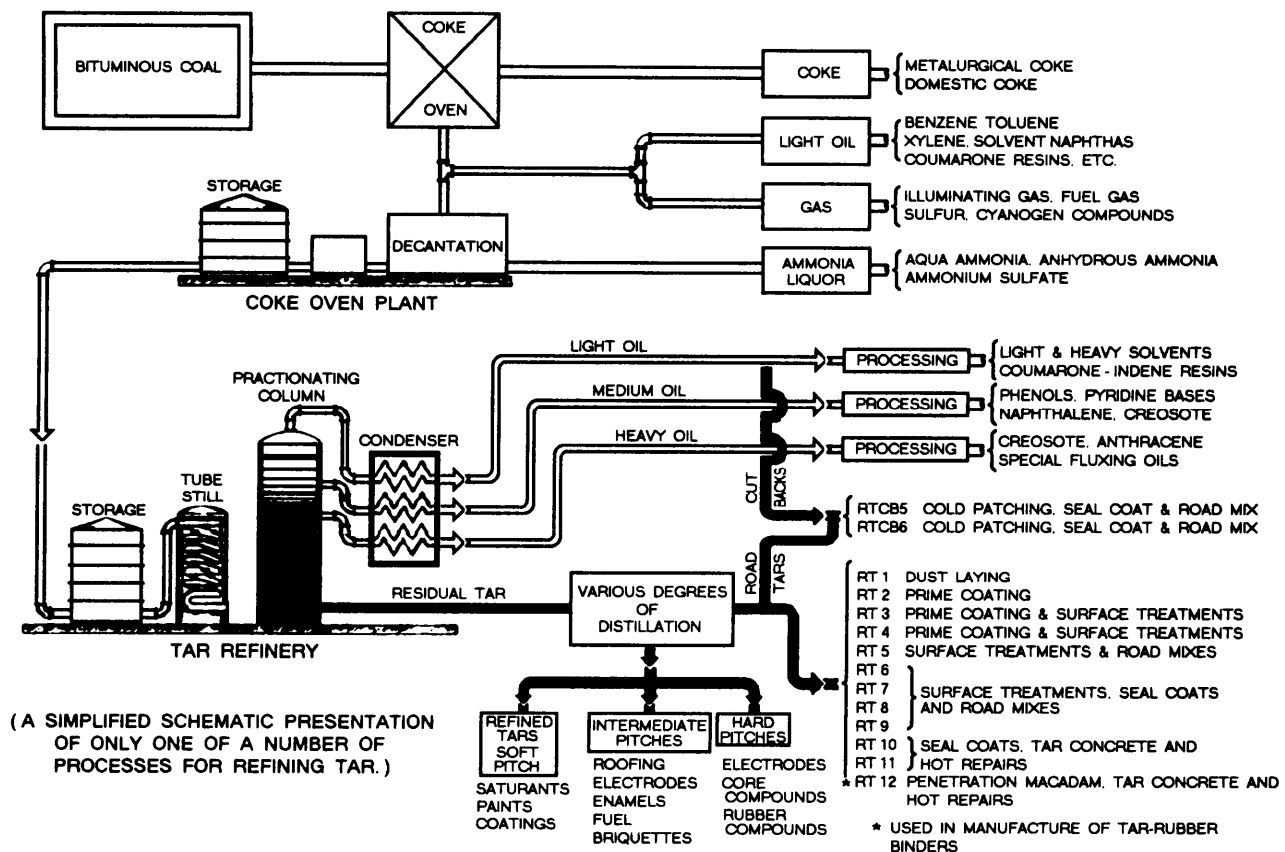


Figure 13-27.-Simplified flow chart showing production of road tars from bituminous coals.

rod is cast into the concrete to be tested. Then the force required to pull the rod from the concrete is measured. The measured strength is the direct shear strength of the concrete. By correlating the shear strength with the compressive strength, a measurement of the in-place strength is made.

BITUMENS AND BITUMINOUS-MATERIALS TESTING

Bituminous pavements are a mixture of well-graded mineral aggregates, mineral filler, and a bituminous cement or binder. They are used as the top portion of a flexible-pavement structure to provide a resilient, waterproof, load-distributing medium that protects the base course from detrimental effects of water and the abrasive action of traffic. This chapter discusses the materials used in the construction of bituminous surfaces and the methods of identifying and testing these materials.

BITUMINOUS-PAVEMENT MATERIALS

Bituminous-pavement materials are made up of a mixture of coarse and fine aggregate, bound together by a liquid or semisolid bituminous binder. The coarse aggregate is stone or gravel that is too large to pass the

No. 8 sieve. The fine aggregate is fine gravel and sand, small enough to pass the No. 8 sieve, but too large to pass the No. 200. Fine rock dust that will pass the No. 200 sieve is called **mineral dust**. A small amount of this may be included in a paving mix, or a small amount of **mineral filler** may be added to the mix. Commonly used mineral fillers are portland cement, pulverized limestone (called limestone dust), silica and hydrated lime.

Aggregates

Aggregates may consist of crushed stone, crushed or uncrushed gravel, slag, sand, and mineral filler, or a combination of some of these materials. Aggregates normally constitute 90 percent or more, by weight, of bituminous mixtures, and their properties have an important effect upon the finished product.

Bituminous Cements

Bituminous cement is the adhesive agent in the bituminous mixture and may be either an asphaltic material or a tar. Asphalt may sometimes be obtained from natural deposits but are most generally obtained from the distillation of crude petroleum (fig. 13-26). Tars are obtained from the destructive distillation of bituminous coal (fig. 13-27). The functions of

Table 13-4.-Penetration Grades and AP Numbers of Asphalt Cement

Penetration grade	AP No.	Relative Consistency
40-50	7	Hard
60-70	5	
85-100	3	Medium
120-150	1	Soft
200-300	00	

bituminous cement are to hold the aggregate particles together and to seal the surface, which then resists the penetration of water.

Bituminous cements are available in several forms suitable for different procedures of mixing or application under wide variations in temperature. Some asphalts and tars are solid or semisolid at room temperature. Other grades are relatively viscous (thick) liquids at room temperatures, and all become liquid at higher temperatures. Mixing bitumens with petroleum solvents or water produces **cutbacks** or **emulsions** that become liquid at atmospheric temperatures. Such liquid asphalts and tars are used for cold mixes or applied as sprays in building pavements.

ASPHALTS.—Asphalts may be natural or manufactured and they may be solid, semisolid or liquid in consistency. Natural asphalts occur in lakes (as lake asphalt), pits, or rock structures (as rock asphalts). Asphalt cement is one of the by-products from the refining of crude petroleum.

Generally, the military engineer depends upon the manufactured asphalts that are obtained when crude petroleum is refined for the purpose of separating the various fractions (fig. 13-26). The crude oil vapors are separated into gasoline, kerosene, and fuel oils, and the residue is asphalt cement and lubricating oils. The longer the process and the higher the temperatures, the harder the residue becomes because of the increased loss in volatiles.

Asphalt cement is commercially available in different standard ranges of consistency (grades). The ranges for the penetration grade are based on measurements by the penetration test in which the relative hardness of asphalt cement is determined by the distance that a standard needle, under a standard loading, will penetrate a sample in a given time under known temperature conditions. The asphalt petroleum (AP) number is a number from 00 to 7 that is assigned

to these penetration ranges. Table 13-4 lists the ranges presently recognized along with relative consistencies corresponding to those ranges.

Asphalt cement is also graded on the basis of viscosity, using special testing equipment (not in the Naval Construction Force Table of Allowance) to measure the time that a given amount of liquid asphalt material will flow through a tube of standard dimensions under rigidly controlled temperature and pressure conditions. Multiplying that measured time by a calibration factor for the equipment gives a numerical designation called **kinematic** viscosity, measured in **stokes** (square centimeters per second) or **centistokes** (stokes 100).

The viscosity grades of asphalt cement are available in two series. One series includes grades AC-2.5, AC-5, AC-10, AC-20, and AC-40. The other series includes grades AR-1000, AR-2000, AR-4000, AR-8000, and AR-16000. Normally, but not always, the lower viscosity-graded asphalts correlate with the softer asphalts having higher penetration values, and the higher viscosity-graded asphalts correlate with the lower penetration grades.

Since all asphalt cements are solid or semisolid at room temperature (77°F), they must be converted in one of three ways to a fluid state before they can be pumped or sprayed through pipes or nozzles and be mixed with aggregate. One way to liquify an asphalt cement is to heat it. Then, when it cools, it becomes a semisolid cementing material. The other methods to liquify asphalt cement are dissolution (producing cutback asphalt) and emulsification (producing emulsified asphalt).

CUTBACKS.—When asphalt cement is dissolved in volatile petroleum solvents (called cutterstock or flux oils), the resulting liquid is known as cutback asphalt. The idea behind cutback asphalt is that upon

Table 13-5.-Asphalt Cutback Composition (Expressed in Percent of Total Volume)

Type	Components		Grades				
		Solvent	30	70	250	800	3000
Rapid curing RC	Asphalt cement	Gasoline or naphtha		65	75	83	87
				35	25	17	13
Medium curing MC	Asphalt cement	Kerosene	54	64	74	82	86
			46	36	26	18	14
Slow curing SC	Asphalt cement	Fuel oil		50	60	70	80
				50	40	30	20

VISCOSITY COMPARISONS

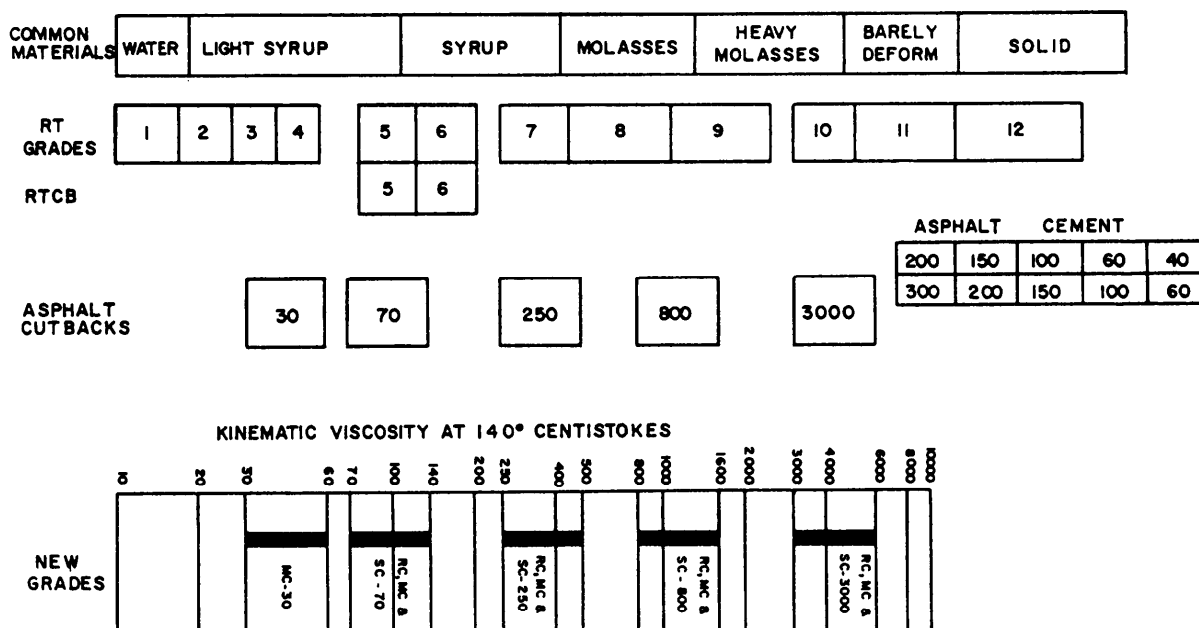


Figure 13-28.-Viscosity grades at room temperature.

exposure to air the solvents evaporate and the asphalt cement is left to perform its function.

The classification of the cutback is based on the rate of evaporation of the distillate that is in the mixture. Gasoline or naphtha (highly volatile) will produce a rapid-curing cutback (RC); kerosene (medium volatility), a medium-curing cutback (MC); and a fuel oil (low volatility), a slow-curing cutback (SC). At times, reference will be found to road oils, which are one of the SC grades of liquid asphalt, or in effect, a heavy petroleum oil. Table 13-5 shows the percentage of components by grade for the three types of asphalt cutbacks.

As more cutterstock is mixed with a given amount of asphalt cement, a thinner liquid results. In practice, different amounts of cutterstock are added to a given

amount of asphalt cement to obtain various viscosities, or grades, of cutbacks. The number assigned to each grade corresponds to the lower limit of kinematic viscosity measured in stokes or centistokes. The upper limit of each grade is equal to twice the lower limit or grade number. Thus a number 70 cutback refers to a viscosity range of 70 to 140 centistokes. The other grades and their limits are 250 (250-500), 800 (800-1600), and 3000 (3000-6000); in addition, the MC has a 30 grade. Figure 13-28 shows the scale of viscosity grades. The higher the viscosity, the thicker the liquid.

Asphaltic penetrative soil binder is a special cutback asphalt composed of low penetration grade asphalt and a solvent blend of kerosene and naphtha. It is similar in character to a standard low viscosity, medium-curing

Table 13-6.-Characteristics of Bituminous Materials

Material	Form	Grade designation	Temperature of application ranges				Flashpoint (min)		Remarks
			Spraying ¹		Mixing		° F.	° C.	
			° F.	° C.	° F.	° C.			
Penetrative Soil Binder Cutback (RC)	Liquid	—	130-150	55-65	—	—	80	27	Contains naphtha. Caution: Highly flammable.
	Liquids—asphalt residues fluxed with more volatile petroleum distillate.	RC-70	105-175	41-79	95-135	35-57	80	27	Rapid curing cutbacks contain highly volatile naphtha cutterstock. Naphtha evaporates quickly leaving asphalt cement binder permitting early use of surface.
		-250	145-220	63-104	135-175	57-79	80	27	
		-800	180-255	82-124	170-210	77-99	80	27	
		-3000	215-290	102-143	200-240	93-116	80	27	
(MC)	do	MC-30	70-140	21-60	55-95	13-35	100	37	Caution: Highly flammable.
		-70	105-175	41-79	95-135	35-57	100	37	Medium curing cutbacks contain less volatile kerosene cutterstock. Kerosene evaporates less rapidly than naphtha.
		-250	145-220	63-104	135-175	57-79	150	65	
		-800	180-255	82-124	170-210	77-99	150	65	Caution: Flammable.
		-3000	215-290	102-143	200-240	93-116	150	65	Slow curing cutbacks contain slightly volatile diesel fuel cutterstock. Diesel fuel evaporates slowly.
(SC)	do	SC-70	105-175	41-79	95-135	35-57	150	65	
		-250	145-220	63-104	135-175	57-79	175+	79+	
		-800	180-255	82-124	170-210	71-99	200+	93+	
		-3000	215-290	102-143	200-240	93-116	225+	107+	Caution: Flammable.
Asphalt Cements (AC)	Solids	40-50			300-350	149-177			Penetrations 40 to 100 used for crack and joint fillers. Penetrations 70 to 300 used for plant mixes, penetration macadam, and surface treatment. Use test (TM 5-530) to determine flashpoint.
		60-70	285-350	141-177	275-325	135-163			
		85-100	285-350	141-177	275-325	135-163			
		120-150	285-350	141-177	275-325	135-163			
		200-300	260-325	127-163	200-275	93-135			
Powdered Asphalt (PA)	Hard and solid asphalts ground to powder.								Used with SC to produce extra tough road surfaces.
Asphalt Emulsions (RS)	Liquids—asphalt particles held in an aqueous suspension by an emulsifying agent.	RS-1	50-140	10-60	Nonmixing	10-60			Freezing destroys emulsion. Use for road and plant mixes with coarse aggregates (SS). All emulsions with "K" suffix are cationic.
		RS-2	50-140	10-60	50-140	10-60			
		RS-2K	50-140	10-60	50-140	10-60			
		RS-3K	50-140	10-60	50-140	10-60			
(MS)	do	MS-2	50-140	10-60	50-140	10-60			
		SM-K	50-140	10-60	50-140	10-60			
		CM-K	50-140	10-60	50-140	10-60			
(SS)	do	SS-1	50-140	10-60	50-140	10-60			
		SS-1h	50-140	10-60	50-140	10-60			
		SS-K	50-140	10-60	50-140	10-60			
		SS-Kh	50-140	10-60	50-140	10-60			
Road Tars (RT)	Liquids	RT-1	60-125	15-52					Priming oils. RT-4 through RT-12 not generally used.
		RT-2	60-125	16-52					
		RT-3	80-150	27-66					
Road Tar Cutbacks (RTCB)	do	RTCB-5	60-120	16-49					Patching mixtures.
		RTCB-6	60-120	16-49					Caution: Flammable.
Rock Asphalt	Solids								Mixed and used locally where found. Cutback may be added if necessary.

¹ Low temperature is based on a viscosity of 300 centistokes kinematic viscosity and the higher temperature is based on a 50 centistokes viscosity.

² RC Cutbacks are seldom used for spraying.

cutback asphalt, but differs in many specific properties. It is used as a soil binder and dust palliative.

EMULSIONS.— Emulsification is the third process in which asphalt is liquified. In the emulsification process, hot asphalt cement is mechanically separated into minute globules and is dispersed in water that is treated with a small quantity of an emulsifying agent, such as soap, colloidal clay, or one of numerous other organic agents. The rate at which the asphalt globules separate from the water is called the **breaking** or setting time. This rate is generally dependent upon the emulsifier used and the proportion of water to asphalt.

Based in the breaking time, emulsions are described as rapid setting (RS), medium setting (MS), and slow

setting (SS). They are also described by viscosity numbers (fig. 13-28).

Emulsions are also grouped according to their ability to mix with damp aggregate. The RS emulsion breaks so fast that it cannot be mixed; therefore, it is called a nonmixing emulsion. The MS and SS emulsions break slowly enough to permit good mixing; that is, each particle of the aggregate is uniformly coated. Emulsions may be satisfactorily used as a tack coat for bituminous pavements.

ROAD TARS.— Tars are products of the distillation of coal. No natural sources of tar exist. **Coal tar** is a general term applied to all varieties of tar obtained from coal. It is produced by one of several methods, depending on the desired end product. When

Table 13-7.—Typical Uses of Bituminous Materials

Purpose or use	Grade or designation					
	CB - Asphalt cutback ²			AC Asphalt cement with a penetration of -	AE Anionic and cationic asphalt emulsion	RT-RTCB Road tar and road tar cutback
	RC Rapid curing	MC Medium curing	SC Slow curing			
Dust palliative -----	DCA-70 ³	MC-30, 70, 250 A.P.S.B. ⁴	SC-70, 250 -----	-----	SS-1, 1h -----	RT-1 -----
Prime coat:						
Tightly bonded surfaces -----	-----	MC-30 -----	-----	-----	-----	RT-2 -----
Loosely bonded - fine grained surfaces -----	-----	MC-70 -----	SC-70 -----	-----	-----	RT-3 -----
Loosely bonded - coarse grained surfaces -----	-----	MC-250 -----	SC-250 -----	-----	-----	RT-4 -----
Tack coat -----	RC-250, 800 -----	MC-250, 800 --	-----	200-300 -----	RS-1, 2 -----	RT-4, 5, 6, 7, 8, 9
Surface treatment and seal coat:						
Coarse sand cover -----	RC-70, 250 -----	MC-250, 800 --	-----	-----	RS-1, 2 -----	-----
Clean coarse aggregate cover -----	RC-250, 800, 3000	MC-800 -----	-----	120-150, 200-300 -----	-----	RT-6, 7, 8, 9, 10
Graded gravel aggregate cover -----	-----	MC-250, 800 --	SC-800 -----	-----	-----	-----
Gravel mulch -----	-----	MC-250 -----	SC-250 -----	-----	-----	-----
Mixed in-place - Roadmix:						
Open-graded aggregate:						
Sand -----	RC-70, 250 -----	MC-800 -----	-----	-----	-----	RT-6 -----
Maximum diameter 1 in., high percentage passing No. 10. -----	-----	MC-800 -----	-----	-----	MS-2 -----	-----
Macadam aggregate -----	RC-250, 800 -----	-----	-----	85-100 -----	MS-2 -----	RT-7 -----
Dense-graded aggregate:						
High percentage passing No. 200 --	-----	MC-250 -----	SC-250 -----	-----	SS-1h -----	RT-5, 6, 7 -----
Maximum diameter 1 in., medium percentage passing No. 200. -----	-----	MC-250, 800 --	SC-250, 800 -----	-----	SS-1 -----	RT-6, 7, 8, 9
Premix or cold patch:						
Open-graded aggregate -----	RC-250 -----	MC-800 -----	SC-800 -----	-----	MS-2 -----	RT-5, 6, 7, 8 or
Dense-graded aggregate -----	-----	MC-250 -----	SC-250 -----	-----	-----	RTCB-5, 6 -----
Cold-laid plant mix:						
Open-graded aggregate:						
Sand -----	RC-250, 800 -----	-----	-----	-----	MS-2 -----	-----
Maximum diameter 1 in., high percentage passing No. 10. -----	RC-800 -----	-----	SC-800 -----	-----	MS-2 -----	-----
Macadam aggregate -----	RC-800, 3000 -----	-----	-----	-----	-----	-----
Dense-graded aggregate:						
High percentage passing No. 200 -----	-----	MC-800 -----	SC-800 -----	-----	SS-1 -----	RT-5, 6, 7, 8, 9 ---
Maximum diameter 1 in., medium percentage passing No. 200. -----	-----	MC-800 -----	SC-800 -----	-----	SS-1 -----	-----
Aggregate precoating followed with asphalt -----	-----	MC-30 -----	SC-70 -----	-----	-----	-----
Hot-laid plant mix -----	RC-3000 -----	MC-3000 -----	SC-3000 -----	85-100, 120-150 -----	-----	RT-11, 12 -----
Penetration macadam:						
Cold weather -----	RC-800, 3000 -----	-----	SC-3000 -----	120-150 -----	RS-1 -----	RT-10, 11 -----
Hot weather -----	-----	-----	-----	85-100 -----	RS-1 -----	RT-12 -----

¹ Prevailing temperature during construction also affects selection of bitumen and may be the determining factor rather than size and gradation of aggregate.

² Caution: Do not overheat aggregate when cutbacks are used to produce hot mixes.

³ DCA-70 is a water emulsion of a polyvinyl acetate containing chemical modifiers (formerly UCAR-131). Proprietary product of Union Carbide Corporation, New York, N.Y.

⁴ Asphaltic penetrative soil binder.

bituminous coal is destructively distilled, coke and gas are formed, and tar, ammonia, light oils, sulfur, and phenol may be recovered. Coke-oven tar is produced in the greatest amount, and its chemical, physical, and adhesive characteristics make it most suitable for road-tar purposes. Water-gas tar is obtained in the manufacture of carbureted (mixed with hydrocarbons) water gas. The nature of the carbureting oil largely determines the character of the water-gas tar produced. This tar may vary widely in specific gravities, viscosities, and other physical and chemical properties.

Road tars are manufactured in 12 grades of viscosity (figs. 13-27 and 13-28). There are also some special grades for use in rubberized-tar binders. Grades 1 through 7 are liquid at room temperature, and grades 8 through 12 are semisolid or solid. The difference occurs because of different amounts of the liquid coal distillates in the tar; the more distillate, the more liquid (or less solid) the tar. The **road-tar cutbacks** (RTCBs) are the products of cutting back the heavier or harder grades

with coal tar distillates. Road-tar cutbacks are manufactured in two viscosity grades (5 and 6) only.

Tar, which is insoluble in petroleum distillates, is sometimes mixed with oil-resistant, unvulcanized rubber to form a rubberized-tar binder material.

CHARACTERISTICS AND USES OF BITUMENS

Selection of a particular bituminous material depends upon the type of pavement, climatic conditions, seasonal factors, and availability of equipment. In general, soft penetration grades of asphalt cement are preferred for use in cold climates, medium grades in moderate climates, and hard grades in warm climates. Heavier grades of asphalt cutbacks and tars are normally used in warm weather and lighter grades in cold weather.

Tables 13-6 and 13-7 list the bituminous materials, sources, curing, temperatures, and grades associated with bituminous operations.

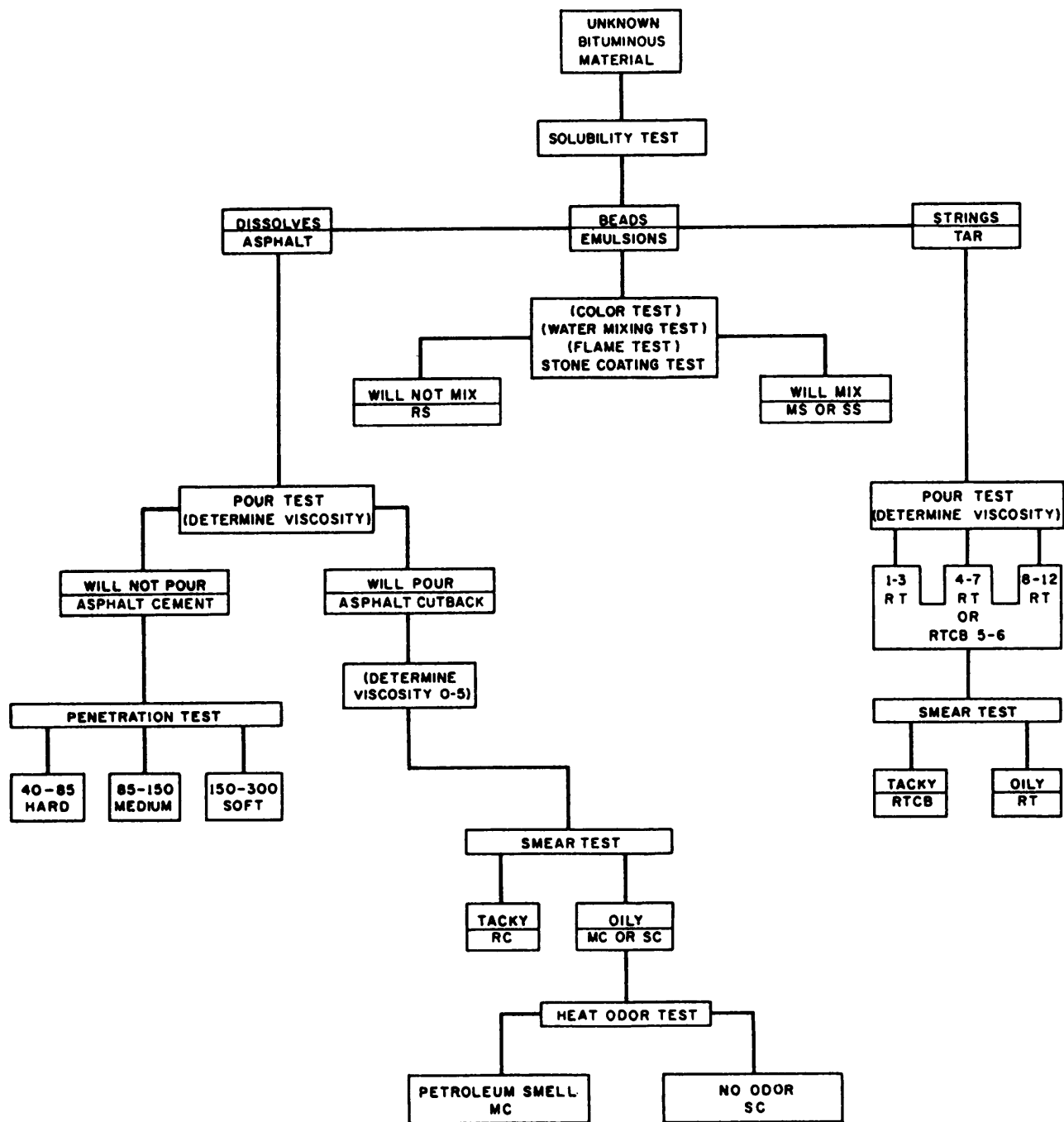


Figure 13-29.-Field identification of unknown bituminous materials.

Advantages and disadvantages of the bituminous materials used in construction are discussed.

Asphalt cement cutbacks are flammable. Also, all asphalts can be dissolved by petroleum products that may be spilled on them, such as during refueling at an airfield. Tars, on the other hand, are not affected by petroleum derivatives since they are products of coal. Tars, when used as a prime for base courses, also seem to possess better penetration qualities than asphalts. Tars

are very temperature-susceptible, having a wide range in viscosity with normal ambient temperature changes. Tar can become so soft during warmer weather that the pavement will rut under traffic. In colder weather it can become so brittle that the pavement will crack.

Asphalt emulsions are not flammable and are liquid at normal temperatures. Since they are mixed with water, they can be used with a damper aggregate than required for the cutbacks. Additional water may be

added to the emulsion up to proportions of 1:3 for use in slurry seal coats. Because emulsions contain water, they have certain disadvantages. During freezing weather the emulsions can freeze, and the components can separate. Also, emulsions are difficult to store for extended periods because they tend to “break” even in unopened drums. When emulsions are shipped, the water in the mixture takes up valuable space, which could be used to transport hard-to-obtain materials.

FIELD IDENTIFICATION OF BITUMENS

A fairly accurate identification of bituminous materials is necessary to make decisions regarding types and methods of construction, types and quantities of equipment, and applicable safety regulations. Field tests must be performed to identify a bituminous material as asphalt cement, asphalt cutback asphalt emulsion, road tar, or road-tar cutback and to field-identify the grade. Field identification of bitumens is summarized in figure 13-29.

Test for Solubility

The first procedure in the identification of an unknown bituminous material is to determine whether it is an asphalt, an emulsion, or a tar. Bituminous materials may be differentiated by a solubility test. To perform the test, you simply dissolve an unknown sample (a few drops, if liquid, or enough to cover the head of a nail, if solid) in any petroleum distillate. Kerosene, gasoline, diesel oil, or jet fuel is suitable for this test. One or more of these distillates is usually available to the EA in the field. Since asphalt is derived from petroleum, it will dissolve in the petroleum distillate. If the material is an emulsion, it can be detected by the appearance of small black globules, or beads, which fall to the bottom of the container. Road tar will not dissolve. If the sample is an asphalt, the sample-distillate mix will be a dark, uniform liquid. If it is a road tar, the sample will be a dark, stringy, undissolved mass in the distillate. You can make a check by spotting a piece of paper or cloth with the mix. If no stain results, the material is a tar; however, if a brown to black stain appears, then it is asphalt. The solubility test provides a positive method of identification.

Tests for Asphalt Cement

When the solubility test determines that the bituminous material is an asphalt you should then perform a **pour test** to distinguish whether the asphalt material is asphalt cement or asphalt cutback. In this test

you place a small sample of asphalt into a container and attempt to pour it at room temperature (77°F). Since asphalt cement is a solid at room temperature, it will not pour. Even the highest penetration grade (200 to 300) will not pour or immediately deform. The thickest asphalt cutback, however, will start to pour in 13 seconds at a temperature of 77°F.

The various grades of asphalt cement are distinguished by their hardness, as measured by a **field penetration test**. For purposes of field identification, the consistency of asphalt cement may be approximated at room temperature as hard (penetration 40-85), medium (penetration 85- 150), and soft (penetration 150-300). These limitations are flexible, as complete accuracy is not essential. You can make an approximation of the hardness while in the field by attempting to push a sharpened pencil or nail into the asphalt at 77°F with a firm pressure of approximately 10 pounds. When the pencil point penetrates with difficulty or breaks, the asphalt cement is hard. When it penetrates slowly with little difficulty, the asphalt cement is medium. If the pencil penetrates easily, the asphalt cement is a high penetration or soft grade.

Tests for Asphalt Cutbacks

In addition to distinguishing asphalt cement from asphalt cutback as discussed above, the pour test will identify the viscosity grade of the cutback at a room temperature of 77°F. After the pour test, the approximate viscosity grade of the cutback is known, but the actual type (RC, MC, SC) is not. Asphalt cement is “cut back” with a petroleum distillate to make it more fluid. If the material does not pour, it is an asphalt cement. If it pours, it is a cutback or emulsion. It has been found that the cutbacks of a given viscosity grade will pour like the following substances:

30 - Water

70 - Light syrup

250- syrup

800- Molasses

3000- Barely deform

A **smear test** is used to distinguish an RC cutback from an MC or SC cutback. The test is based on the fact that RCs are cut back with a highly volatile material (naphtha or gasoline) that evaporates rapidly. To perform the test, you simply apply a thin smear of the material on a nonabsorbent surface, such as a piece of

glazed paper. If the material is an RC, most of the volatiles will evaporate within 10 minutes, and the surface of the smear will become extremely tacky. This is not so for the lighter MC or SC grades, which remain fluid and oily for some time-for hours or days, in some cases. An 800- or 3000-grade MC or SC cutback however, also may become sticky in a few minutes. That is because these grades of cutback contain such small amounts of cutterstock, therefore, you should confirm the identification of the sample by a prolonged smear test.

A **prolonged smear test** is used to identify the 800 and 3000 grades of MC or SC cutback. In this test, a thin smear of asphalt cutback is placed on a nonabsorbent surface and allowed to cure for at least 2 hours. If at the end of that time, the smear is uncured and still quite tacky, the material is an MC or SC; however, if the smear is hard and only slightly tacky, then the material is not an MC or SC. An RC 3000 cutback will cure completely in 3 hours and an RC 800 in about 6 hours; but, an MC or SC will still be sticky even after 24 hours.

The odor given off from a heated cutback helps differentiate an MC (cutback with kerosene) from an SC (cutback with fuel oil). In the **heat-odor test**, you heat the unknown sample in a closed container to capture the escaping vapors. (**Use MINIMAL heat.**) An MC sample will give off a strong kerosene odor. An SC sample will not smell of kerosene, but may have a slight odor of hot motor oil.

Tests for Asphalt Emulsions

You can distinguish asphalt emulsions from other bitumens in various ways as follows:

1. By observing the color of the material. Emulsions are dark brown in color, but other bitumens are black.
2. Emulsions mixed in kerosene or some other petroleum distillate can be detected by the appearance of small black globules, or beads, which fall to the bottom of the container.
3. When an emulsion is mixed with water, the emulsion will accept the extra water and still remain a uniform liquid. Other bitumens will not mix with water.
4. Since an emulsion contains water, a small piece of cloth saturated with it will not burn. Other bitumens will burn or flame.

Once you have established that a bitumen in question is an emulsion, you can then determine whether it is a mixing grade (medium or slow setting) or a

nonmixing grade (rapid setting). To do so, attempt to mix a small amount (6 to 8 percent by weight) of the emulsion with damp sand, using a metal spoon. A fast-setting (RS) emulsion will not mix with the sand, but a medium-setting (MS) or slow-setting (SS) emulsion will readily mix and completely coat the sand. Identifying the emulsion as a mixing or nonmixing type is sufficient for field conditions. Difference in viscosity is unimportant since there are so few grades. No distinction is necessary between MS and SS emulsions because both are mixing types and are used largely for the same purpose.

Tests for Tars

A **pour test** is used to identify the viscosity grades of tar. Viscosity grades of road tars are comparable to the viscosity grades of asphalt cutbacks and asphalt cement, as shown in figure 13-28. RT-1, the most fluid, is similar in viscosity to the MC-30 asphalt cutback. RT-8 is similar to grade 800 asphalt cutback. RT-12 has the approximate consistency of asphalt cement; that is, 200 to 300 penetration.

Referring again to figure 13-28, you see that road tars RT-4 to RT-7 and road-tar cutbacks RTCB-5 and RTCB-6 have similar viscosities; therefore, if an identified tar has a viscosity range of RT-4 to RT-7, you must perform a smear test to distinguish whether it is a road tar or a road-tar cutback. The test is performed in the manner previously described for cutback asphalt. Like rapid-curing cutback asphalts, road-tar cutbacks are thinned with highly volatile materials, which evaporate quickly, leaving a sticky substance within a 10-minute period. On the other hand, because the fluid coal oil in road tars evaporates slowly, road tars will remain at about the same consistency at the end of an identical period. It is not important to determine whether the road-tar cutback is RTCB-5 or RTCB-6 since both are used under approximately the same conditions.

LABORATORY TESTS OF BITUMENS

Laboratory testing provides a more positive identification of bituminous materials than is possible with field testing. That, however, is not the only purpose of the various laboratory tests. For example, specific gravity testing (discussed in NAVFAC MO-330) is sometimes needed for the purpose of other tests and for checking the uniformity of successive asphalt shipments. Other tests are performed for mix design purposes, for checking compliance with project

specifications, and for establishing safe handling procedures.

Bituminous materials are manufactured to meet specifications established by the federal government, American Association of State Highway and Transportation Officials (AASHTO), and American Society for Testing and Materials (ASTM). These specifications define the extreme limits permitted in the manufacture of the material and assure the user that the material will possess definite characteristics and fulfill the project requirements. Some of the different tests the EA should be able to perform in the laboratory are discussed below. Other tests that you are less likely to perform, but should be aware of, are discussed in NAVFAC MO-330.

Identification Tests

The laboratory identification kit for bitumens consists of a number of jars containing samples of bitumens in all the recognized categories. To use this kit, you must bring an unidentified sample to approximately the same temperature as the kit samples, and then, following instructions that come with the kit, make identification on the basis of similarity of color, feel, consistency, and odor.

A bituminous material suitable for use in pavement has a considerably higher ductility (which may be roughly defined as stretchability) than one that is suitable only for use as a waterproofer, roofing binder, or crack filler. Any crude method of determining the presence or absence of ductility (such as stretching the material like an elastic) will indicate whether or not the unidentified samples lies somewhere in the category of pavement material.

Distillation Test

If the unknown bitumen proves to be an asphalt and has an odor that indicates the presence of a distillate (such as the odor of kerosene or naphtha), a **distillation test** will indicate the character and approximate grade. In making this test, bear in mind that the basic material for RC and MC is asphaltic cement; that is, penetration asphalt. The basis for SC, however, is not asphaltic cement, but an asphalt residual oil too fluid to be penetration-tested for grade.

RC, MC, and SC all contain a distillate; that is, a volatile liquid that evaporates during the curing process. For RC and MC, the distillate is highly volatile and evaporates quickly; for SC, it is considerably less volatile.

The grade of RC, MC, or SC increases with the ratio of bitumen to distillate. Obviously, the higher the percentage of bitumen, the more solid the material will be, and, therefore, the higher the grade. For RC and MC, the percentage of bitumen for a given grade is the same, as shown in the following example:

Grade	30	70	250	800	3000
Percentage bitumen	54	64	74	82	86

These figures mean that for MC-30, for example, the percentage of bitumen is 54—the percentage of distillate being determinable, of course, by subtracting the percentage of bitumen from 100.

For SC the bitumen percentages are somewhat lower as follows:

Grade	70	250	800	3000
Percentage bitumen	50	60	70	80

From the distillation test, you can determine the bitumen percentage and whether the material is SC, RC, or MC. If it turns out to be RC or MC, the speed with which the distillate evaporates during the test (naphtha or gasoline will evaporate much more rapidly than kerosene) will indicate whether it is RC or MC.

Figure 13-30 shows the apparatus used in distillation testing. A measured quantity (measured by volume) of the bitumen is placed in a distillation flask

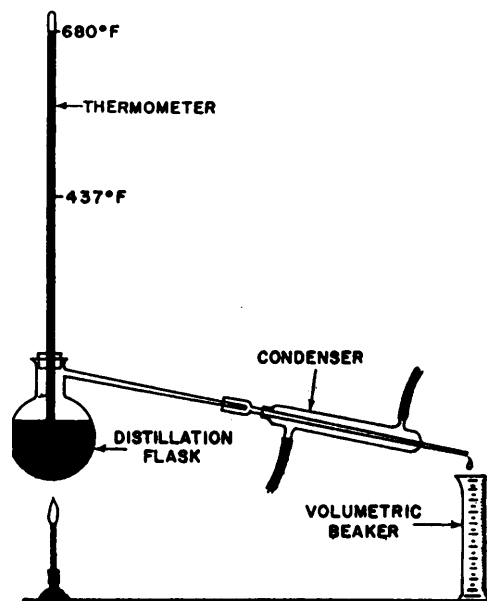


Figure 13-30.-Apparatus for distillation testing.

that has a thermometer running through the stopper, as shown. The flask and contents are heated. As the temperature rises, distillate is given off in the form of vapor. A condenser returns the vapor to liquid form, and the liquid (the distillate) is caught in a volumetric beaker. The test indicates what can be expected in the application and use of the materials. The distillation temperature ranges from 374°F to 680°F for RC asphalt cutbacks, from 437°F to 680°F for MC, and only at 680°F for SC. Road tars are distilled at temperatures that range from 338°F to 572°F, and tar-rubber blends from 170°F to 355°F. The amount distilled is expressed as a percentage of the total. The residue is the difference between the distillate and the total. The percentages of distillation may be as little as 1 percent for tar-rubber distilled at 170°C (338°F) to as much as 59 percent when RC and MC cutbacks and tars are heated to the higher temperatures.

Record the volume of bitumen remaining in the flask. If the residue is solid enough to be tested, it is subjected to the penetration test described later in this chapter. If it is solid enough for this test, the residue must be asphaltic cement, and the original material was either RC or MC. If it is not solid enough for penetration testing, the original material was SC.

Finally, you can determine the grade by calculating the percentage of bitumen and comparing it with the ranges previously given.

Flash Point Tests

The **flash point** of a bitumen that contains a volatile distillate is the temperature at which it begins to give off ignitable vapor. The principal purpose of flash-point testing is to determine maximum safe mixing and applying temperatures; however, these tests are an aid to identification as well. Referring again to table 13-6, you see that RC and MC have flash points below 175°F. MC-30 and SC-70 have flash points around 150°F, but the other grades of SC have flash points above 175°F.

Testing for a flash point below 175°F is done with the **tag open-cup** equipment shown in figure 13-31. When testing for flash points above 175°F, use the **Cleveland open-cup** equipment shown in figure 13-32. When using either of these testers, you need to follow the procedures described in NAVFAC MO-330. While there are important procedural differences, flash-point testing using either equipment is similar in that you use the equipment to heat the test sample at a prescribed rate of temperature increase. Then, when the temperature reading on the thermometer nears the estimated flash

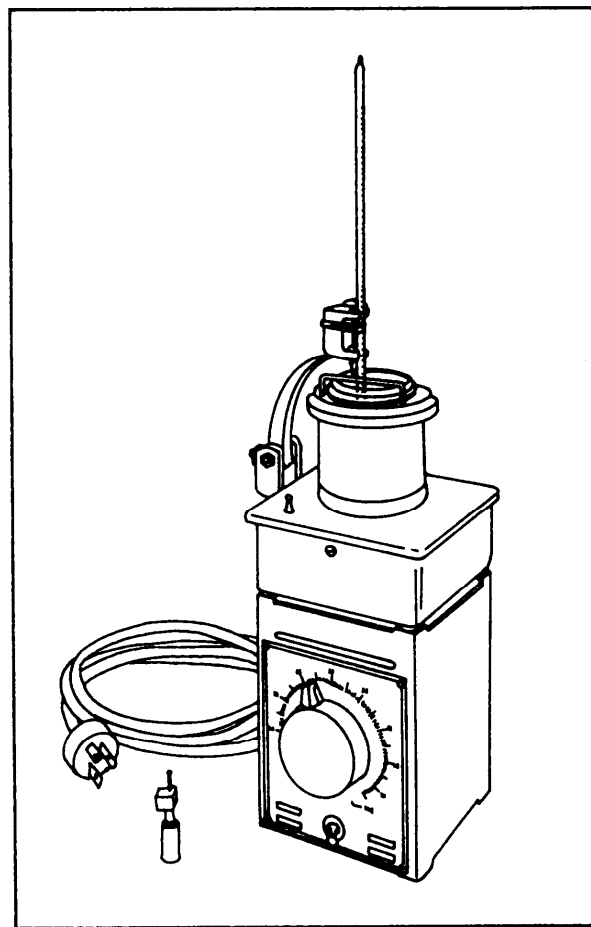


Figure 13-31.—Tag open-cup flash point tester.

point (table 13-6), you use an alcohol torch to begin passing a flame across the surface of the sample. The flash point is reached when the test flame produces a distinct flicker or flash on the surface of the sample. At this point you read the thermometer and record the temperature.

Penetration Test

Figure 13-33 shows an asphalt penetrometer that is used to determine the grade of asphalt cement. In performing the test, the needle is carefully brought to contact with the surface of the sample, then released so as to exert a pressure of 100 grams. The seconds after the needle is released, the distance it penetrated the sample is read, to the nearest 0.01 centimeter, on the penetrometer dial. The reported penetration is the average of at least three tests on the same material whose values do not differ more than four points between maximum and minimum. Detailed procedures can be found in NAVFAC MO-330.

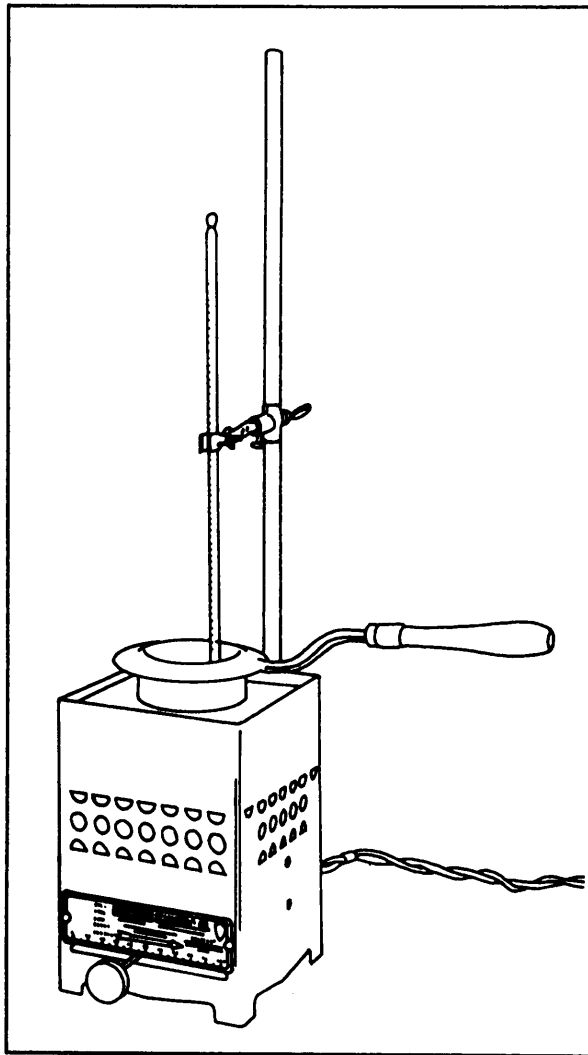


Figure 13-32.-Cleveland open-cup flash point tester.

In addition to grade determination, the penetration test is useful for other purposes, such as detecting overheating or prolonged heating of asphalts in storage tanks. Also, when the asphalt is extracted from a pavement, the penetration test is useful in determining how the asphalt has changed with age and weathering.

TESTS ON AGGREGATE

The desired characteristics of aggregates used for bituminous paving include angular shape, rough surface, hardness, and gradation. These qualities and grain distribution largely affect the quality of the resulting pavement. The larger, coarse aggregate particles are the main structural members of the pavement; however, if there were nothing but large particles, there would be many unfilled voids between adjacent particles. The fewer voids the mixture has, the more dense the pavement and, therefore, the more

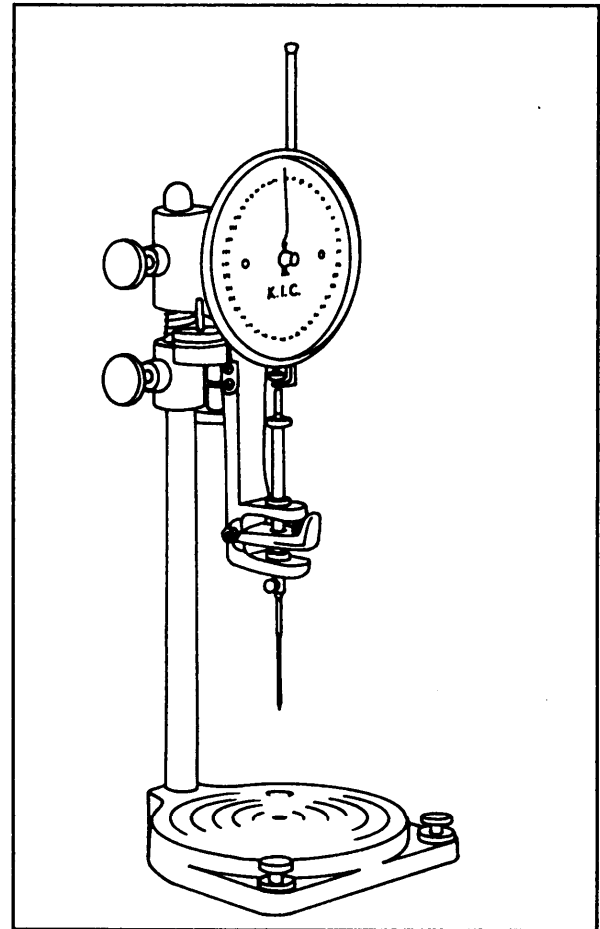


Figure 13-33.-Asphalt penetrometer.

durable it is. Ideal density is obtained by filling the voids between the largest particles with smaller particles, and soon, right down through the whole range of sizes from coarsest to finest.

Common practice divides the aggregates used for bituminous paving into coarse aggregate (retained on the No. 10 sieve), fine aggregate (retained on the No. 200 sieve), and mineral filler. Usually 65 percent or more of the mineral filler will pass the No. 200 sieve. The distribution of the sizes determines how many voids will remain and aids in determining how much bitumen will be needed.

The EA must be able to perform a number of tests on aggregates to determine their acceptability for bituminous construction. One test is the grain size distribution test that is done by sieve analysis, using the same procedure as described for soil in the EA3 TRAMAN. Tests for mineral dust and specific gravity are also needed. Instructions for conducting both these tests are contained in the following paragraphs.

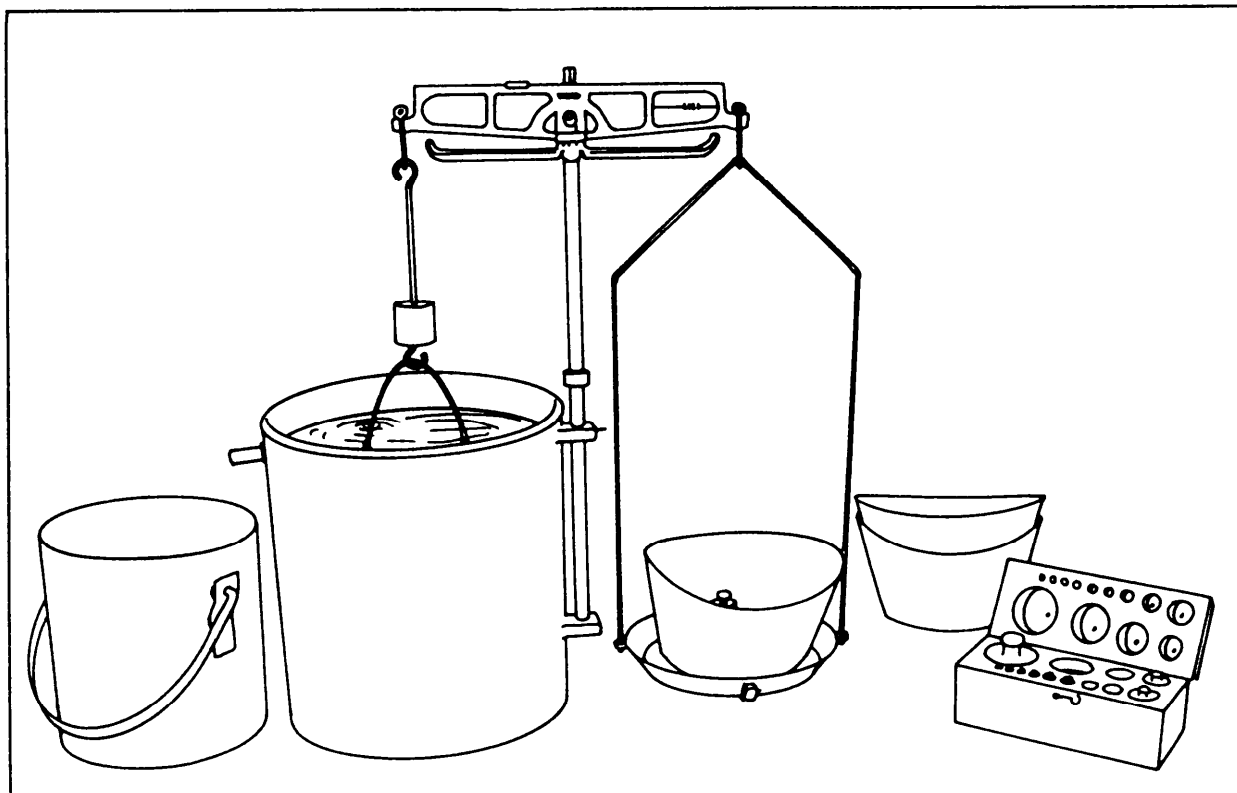


Figure 13-34. Dunagan apparatus for specific gravity test.

Test for Mineral Dust

In bituminous paving, particles finer than the No. 200 sieve are referred to a **mineral dust**. To measure the amount of mineral dust in a selected sample, you perform a washed sieve analysis (discussed in the EA3 TRAMAN), using the No. 40 and No. 200 sieves. After all the material possible has passed the No. 200 sieve and has been discarded, the materials remaining on the sieve are returned to the original washed sample, oven-dried, and weighed. The amount of mineral dust is then calculated, using the following formula:

$$\text{Percent finer than No. 200} = \frac{W_o - W_w}{W_o} \times 100$$

Where:

W_o = Original dry weight

W_w = Washed dry weight

Tests for Specific Gravity

The specific gravities of aggregates used in bituminous paving mixtures are required in the computation of the percent of air voids and percent of

voids filled with bitumens. Apparent specific gravity used with aggregate blends showing water absorption of less than 2 1/2 percent is based upon the apparent volume of the material, which does not include those pore spaces in the aggregate that are permeable to water. Bulk-impregnated specific gravity is used for aggregate blends with 2 1/2 percent or greater water absorption. The methods for determining absorption were discussed earlier in this chapter in the discussion of concrete aggregates.

The apparent specific gravity can be determined using the methods described in NAVFAC MO-330 for apparent and bulk specific gravity. It may also be determined using the Dunagan apparatus shown in figure 13-34. The procedures are as follows:

1. Select approximately 5,000 grams of aggregate from the sample, not including particles smaller than the 3/8-inch sieve.
2. Wash the aggregate to remove any dust or other coating and dry it to constant weight in the oven. Record the total weight of oven-dry aggregate on the data sheet, as shown in figure 13-35.
3. Immerse the aggregate in water at 15°C to 25°C for a period of 24 hours.

SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS		DATE <u>19 JUN 199-</u>	
PROJECT <u>CAMP COVINGTON</u>		JOB <u>ROAD "A"</u>	
COARSE AGGREGATE		UNITS (Grams)	
MATERIAL PASSING <u>1"</u> SIEVE AND RETAINED ON <u>16</u> SIEVE			
SAMPLE NUMBER	<u>CA</u>		
1. WEIGHT OF OVEN - DRY AGGREGATE	<u>378.3</u>		
2. WEIGHT OF SATURATED AGGREGATE IN WATER	<u>241.0</u>		
3. DIFFERENCE (Line 1 minus 2)	<u>137.3</u>		
APPARENT SPECIFIC GRAVITY, $G = \frac{(\text{Line 1})}{(\text{Line 3})}$		<u>$\frac{378.3}{137.3} = 2.755$</u>	
FINE AGGREGATE		UNITS (Grams)	
MATERIAL PASSING NUMBER <u>3/8"</u> SIEVE			
SAMPLE NUMBER	<u>FRBS</u>		
4. WEIGHT OF OVEN - DRY MATERIAL	<u>478.8</u>		
5. WEIGHT OF FLASK FILLED WITH WATER AT 20° C	<u>678.6</u>		
6. SUM (Line 4 + 5)	<u>1157.4</u>		
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20° C,	<u>977.4</u>		
8. DIFFERENCE (Line 6 minus 7)	<u>180.0</u>		
APPARENT SPECIFIC GRAVITY, $G = \frac{(\text{Line 4})}{(\text{Line 8})}$		<u>$\frac{478.8}{180.0} = 2.660$</u>	
FILLER		UNITS (Grams)	
SAMPLE NUMBER	<u>LSD</u>		
9. WEIGHT OF OVEN - DRY MATERIAL	<u>466.5</u>		
10. WEIGHT OF FLASK FILLED WITH WATER AT 20° C,	<u>676.1</u>		
11. SUM (Line 9 + 10)	<u>1142.6</u>		
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20° C,	<u>973.8</u>		
13. DIFFERENCE (Line 11 minus 12)	<u>168.8</u>		
APPARENT SPECIFIC GRAVITY, $G = \frac{(\text{Line 9})}{(\text{Line 13})}$		<u>$\frac{466.5}{168.8} = 2.762$</u>	
BINDER		UNITS (Grams)	
SAMPLE NUMBER	<u>6873</u>		
14. WEIGHT OF PYCNOMETER FILLED WITH WATER	<u>61.9595</u>		
15. WEIGHT OF EMPTY PYCNOMETER	<u>37.9215</u>		
16. WEIGHT OF WATER (Line 14 minus 15)	<u>24.0380</u>		
17. WEIGHT OF PYCNOMETER + BINDER	<u>47.8617</u>		
18. WEIGHT OF BINDER (Line 17 minus 15)	<u>9.9402</u>		
19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER	<u>62.1568</u>		
20. WEIGHT OF WATER TO FILL PYCNOMETER (Line 19 minus 17)	<u>14.2951</u>		
21. WEIGHT OF WATER DISPLACED BY BINDER (Line 16 minus 20)	<u>9.7429</u>		
APPARENT SPECIFIC GRAVITY, $G = \frac{(\text{Line 18})}{(\text{Line 21})}$		<u>$\frac{9.9402}{9.7429} = 1.020$</u>	
TECHNICIAN (Signature) <u>EA3 A. McDaniel</u>		COMPUTED BY (Signature) <u>EA2 Cutler Price</u>	
CHECKED BY (Signature) <u>EA2 Cutler Price</u>			

DD Form 1216, 1 DEC 65

Figure 13-35.—Data sheet for specific gravity of bituminous mix components (DD Form 1216).

4. After soaking the sample, place it in the bucket, which is filled with water. Then turn the bucket and aggregate sharply back and forth to help remove any air.

5. Suspend the bucket from the brass hanger and bring the water level up to the overflow pipe.

6. Determine the submerged weight using weights placed in the scoop on the right-hand pan. Record the weights in the appropriate spaces on the data sheet. The calculations required for the determination of the apparent specific gravity of coarse aggregate are shown on the data sheet and are self-explanatory.

MIX DESIGN TESTS

Mixture design tests for bituminous pavement are carried out on samples mixed and compacted in the laboratory to determine the optimum bitumen content, the optimum aggregate content, and gradation required to produce a pavement that will meet given quality specifications. Mixes with various bitumen and aggregate contents and gradations are prepared, compacted to specified density, and tested. From the test results, design engineers determine optimum values.

Mix design test procedures vary considerably. This course can give only a general description of typical procedures. Mixture design is more fully discussed in NAVFAC MO-330 and at the EA1 level in Part 2 of this TRAMAN.

Selection of Sample Bitumen Contents

Bitumen content for laboratory test mixes must be estimated to get the tests started. Tests are made with a minimum of five contents: two above, two below, and one at a content estimated to be about right. Bitumen content is expressed in terms of percentage of bitumen by weight to the total weight of the mix. Percentages commonly run from 3 to 7, depending upon the type of binder used and the specification requirements.

Preparation of Aggregate

A quantity of aggregate of the selected blend sufficient to make the required number of test samples is dried at 230°F. The dry aggregate is separated into several size ranges by sieving, and a sieve analysis is then made of each range.

From this procedure, design engineers can determine trial percentages for test blends. Test blends are then made with these trial percentages. Again, a

sieve analysis is made, this time to determine a blending gradation, such as shown in figure 13-36.

The explanation of figure 13-36 is as follows. The aggregate here was first sifted into four categories: coarse, fine, fine river bar sand (FRBS), and limestone dust (LSD)-the last being a commonly used mineral filler. All of the coarse aggregate consisted of material that would not pass the No. 8 sieve; 89.5 percent of fine aggregate consisted of material that would not pass the No. 80 sieve; and 90 percent of the FRBS consisted of material that would not pass the No. 200 sieve. These three sieves, then, were the ones used to make the original broad separation. Limestone dust was added to the extent of 2 percent.

After the sample was broadly divided, a sieve analysis was made of each broad division category, as shown. This analysis was studied by experts, who estimated, among other things, the probable void percentages that would exist in pavements made with the aggregate used in various combinations. Percentages that would minimize void percentages were estimated.

For trial blend No. 1, these percentages are listed under "percent used." The percentages are 27 coarse, 63 fine, 8 FRD, and 2 LSD. A blend containing these percentages was made, and again the material in each category was sieve-analyzed, as shown. From these individual analyses, the blend analysis (that is, the sieve analysis for the mixed blend) was determined by adding together the percentages in each column.

Thus an aggregate gradation for the blend was obtained. If tests showed that this particular gradation produced a mix that met the specifications for the pavement, this gradation would be specified for the aggregate used in the highway.

Specimen Mixing and Compacting for Testing

To prepare an aggregate blend for testing, thoroughly mix and heat enough blend for two specimens (about 3,000 grams) to the desired mixing temperature. Trough the aggregate blend; then heat the test amount of bitumen to mixing temperature and pour it into the trough. Mix the aggregate and bitumen together thoroughly with a mechanical mixer if one is available. Then place the mix in a compaction mold and compact it with a tamper. Give the number of blows required to produce the density that will be attained under the traffic for which the pavement is being designed. NAVFAC DM-5.4, *Civil Engineering*, specifies 50 blows for secondary roads and 75 blows for

BITUMINOUS MIX DESIGN - AGGREGATE BLENDING											DATE 29 AUG 199	
PROJECT HIGHWAY #203						JOB #47326			AGGREGATE GRADATION NUMBER 2A			
GRADATION OF MATERIAL												
SIEVE SIZE (To be entered by Technician): →		1	3/4	1/2	3/8	4	8	20	40	80	200	
MATERIAL USED		PERCENT PASSING										
COARSE (CA)			100	70.0	34.5	3.0						
FINE (FA)				100	99.8	90.0	66.0	43.0	27.0	10.5	3.0	
FINE RIVER BAR SAND (FRBS)								100	99.0	80.0	10.0	
LIMESTONE DUST (LSD)									100	99.0	90.0	
DESIRED:												
COMBINED GRADATION FOR BLEND - TRIAL NUMBER 1												
SIEVE SIZE (To be entered by Technician): →		1	3/4	1/2	3/8	4	8	20	40	80	200	
MATERIAL USED		% USED	PERCENT PASSING									
CA		27.0	27.0	18.9	9.3	0.8						
FA		63.0	63.0	63.0	62.9	56.7	41.6	27.1	17.0	6.6	1.9	
FRBS		8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	6.4	0.8	
LSD		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.8	
BLEND:			100	91.9	82.2	67.5	51.6	37.1	26.9	15.0	4.5	
DESIRED:												
COMBINED GRADATION FOR BLEND - TRIAL NUMBER												
SIEVE SIZE (To be entered by Technician): →												
MATERIAL USED		% USED	PERCENT PASSING									
BLEND:												
DESIRED:												

DD Form 1217, DEC 65 PREVIOUS EDITION OF THIS FORM IS OBSOLETE

Figure 13-36. Data sheet for aggregate gradation of trial blends (DD Form 1217).

primary roads. Seventy-five blows produce the equivalent of a tire pressure of 200 psi; 50 blows produce the equivalent of a tire pressure of 100 psi. After the compaction process, place the mold in a bearing-ratio jack and extract the compacted sample with extraction equipment.

Density and Voids Determination

Density of the specimens should be determined by weighing in air and in water. A direct weight in water of open-textured or porous specimens will give erroneous results because of absorption of water, and other means must be used to determine the volume of the specimen. One means of measuring the volume of a porous specimen is to coat the specimen with paraffin to seal

all the voids and then weigh the coated specimen in air and in water. A correction is made for the weight and volume of the paraffin. The difference between these two weights, in grams, gives the volume of the specimen in cubic centimeters. You can then determine the unit weight (density) of the mix in pounds per cubic foot for each specimen by multiplying the specific gravity of the specimen by 62.4 pounds (weight of 1 cubic foot of water). Before carrying out the calculations for percent of voids, you must know the specific gravity of the aggregate blend and the asphalt content used.

Stability and Flow Determination

A full discussion of the method used to test for stability and flow can be found in NAVFAC MO-330;

HAZARDOUS-MATERIAL PRECAUTIONS

Although the Navy has exacting definitions for the terms *hazardous material*, *hazardous chemical*, and *hazardous substance*, let's, for simplicity of discussion, lump them all together and simply say that these materials, because of their quantities, concentration, or hazardous properties, pose a substantial hazard to human safety and health or to the environment. The risks associated with these materials include flammability, toxicity, corrosivity, and reactivity. From your study of this chapter and the EA3 TRAMAN, you should be able to see readily how many of the materials you test, or use for testing, in the laboratory fall within the above definition. Heated asphalt can cause severe burns if allowed to come into contact with the skin, and asphalt cutbacks are highly flammable with low flash points. Some of the chemicals that you will use in materials testing are highly toxic and corrosive. Others react with water, forming explosive gases; however, not all of the hazardous materials that an EA uses are confined to the laboratory. For example, the ammonia used with reproduction equipment gives off highly toxic fumes. For these and other reasons, all such materials must be handled, used, stored, and disposed of properly and with caution. As a crew leader, you must recognize the threat that hazardous materials pose to all personnel present on the jobsite and take action to prevent mishaps.

Material Safety Data Sheets (MSDS) must be received and maintained for all hazardous materials in your work space. The MSDS identifies any hazards associated with exposure to a specific material. It identifies personal protective equipment and other safety precautions required as well as first aid or medical treatment required for exposure. By federal law, a crew leader is required to inform his or her crew members of the risks and all safety precautions associated with any hazardous material present on the jobsite. A good time for you to do this is during your daily standup safety lectures.

A safe practice concerning hazardous materials is to not draw more material than will be used in 1 day. Storing hazardous materials in the workspace or on the jobsite requires the use of approved storage containers. Some of these materials require separate storage; for example, flammable materials and corrosive materials cannot be stored together. When in doubt about storage requirements, consult with your supervisor or the safety officer.

Excess hazardous materials or hazardous waste products must be disposed of through an authorized

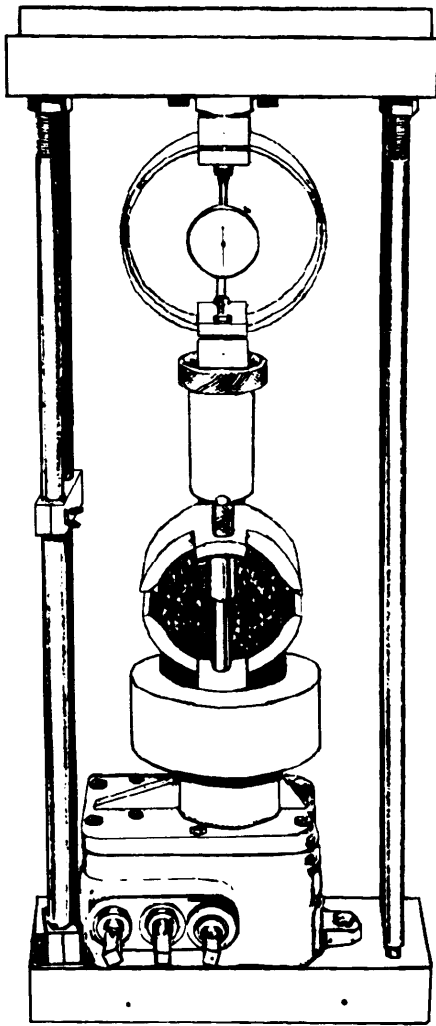


Figure 13-37.-Marshall stability testing head mounted in CBR jack.

however, we'll briefly discuss the method here. The apparatus used for testing stability and flow of the specimen is shown in figure 13-37. This figure shows a Marshall stability testing head containing the specimen, mounted on the plunger of a bearing-ratio jack. This test head consists of upper and lower breaking heads. A 5,000-pound proving ring with a dial is installed in the jack. The test for stability is made by applying pressure gradually, about 2 inches per minute, and reading the maximum pressure the specimen sustains before failing.

The test for flow is carried out simultaneously by holding a flow meter over the testing head guide rod (vertical rod shown running through the testing heads) and reading the meter at the instant the specimen fails under pressure. This reading indicates the flow value of the specimen in inches to the nearest 0.01 inch.

hazardous material disposal facility. Check with your supervisor, safety officer, or hazardous materials representative for proper procedures.

QUESTIONS

- Q1. *What is the primary purpose of soil-compaction testing?*
- Q2. *When performing a compaction test on a sandy soil, (a) what mold should you use and (b) how many tamper blows per layer are required?*
- Q3. *What is the overall objective of density testing?*
- Q4. *In the sand-displacement method of density testing, the sand is calibrated to determine its bulk density. Why must you do this before each test?*
- Q5. *The California bearing ratio (CBR) test measures the capacity of a soil to resist what type of force?*
- Q6. *Of the cements discussed in the TRAMAN, which one is most sulphate resistant?*
- Q7. *When the cement paste in a concrete mix does not bond with the aggregate particles, what is the probable cause?*
- Q8. *When a concrete mix contains an excessive amount of silt or clay, what surface defect may occur when the concrete is placed?*
- Q9. *As related to aggregate used in concrete, define the term surface moisture.*
- Q10. *What is the primary reason for adding an air-entraining agent to a concrete mix?*
- Q11. *Define the term hydration as it applies to concrete.*
- Q12. *In concrete flexural-strength testing, when should you use the formula $R = 3Pa/bd^2$?*
- Q13. *In what three ways can asphalt be liquified?*
- Q14. *To identify an unknown bituminous material what is the first field test that you should perform?*
- Q15. *To distinguish the type and determine the approximate grade of an unknown asphalt cutback, what laboratory test should you perform?*

PART II

EA1 ADVANCED

